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1) SUBJECT OF THE RESEARCH: Experimental Analysis of the Diesel Fuels Performances on the Phenomenon of the Deposits Formations.

2) NAME OF CONTRACTOR: Università di Napoli - Istituto di Meccanica delle Macchine - Napoli - Italy.

3) CONTRACT NUMBER: DA - 91 - 591 - EUC - 2669

4) TYPE AND NUMBER OF REPORT: Final Tecnical Report.

5) PERIOD COVERED BY THE REPORT: 1st August 1962 - 31th July 1963

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I N D E X

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ABSTRACT

The purpose of this research work is to analyze on experi - mental basis the influence of diesel fuels characteristics on the phenomenon of deposits formation in high-speed diesel engines.

The diesel fuel parameters, which have been investigated, are:

1) Specific gravity.
2) Sulphur content.
3) Cetane number.

The research program included, in a first formulation, 72 engine tests, but, being necessary two years to perform all these engine tests, a restricted research program of twenty tests was elaborated and approved (Contract DA - 91 - 591 - EUC - 2669) so that this restricted program has been performed from the August 1962 to the July 1963.

The execution of the remaining 52 engine tests provided in the first research program is the matter of another Research Contract (DA - 91 - 591 - EUC - 2938), and shall be performed from the August 1963 to the July 1964.

The present Final Report is referred to the research program relative to the first 20 engine tests.

These engine tests have been performed on Petter AV1 engine under standard running conditions.

The engine test plant is that one set up during the research titled "Test of Detergent Additives for Diesel Fuels" (Contract Number DA - 91 - 591 - EUC - 1661 - OI - 7321 - 61). In the Final Report of that Contract are reported the standard test conditions,

that have been followed in performing the 20 engine tests of the present research work.

The influence of the above said characteristics of the diesel fuel has been investigated analyzing the deposits formed on the piston and in the injector nozzle, when the Petter AV1 engine was running with diesel fuel having scheduled values of specific gravity, of sulphur content and of cetane number.

Two gasoils of different specific gravities (0.823 and 0.854 repectively) have been tested: the two gasoils have been obtained from the distillation of a commercial gasoil (specific gravity = 0.835).

The sulphur content of these gasoils has been carried to the desired values by additivation of CS_2, while the scheduled values of the Cetane number of the same gasoils have been obtained by additivation of ethyl-nitrate.

The evaluation of the deposits formed on the piston and in the injector nozzle has been made with the means set up during the research work "Test of Detergent Additives for Diesel fuels."

The results of these 20 engine tests are not conclusive in regard to the influence of the characteristics of the gasoil on the phenomenon of deposit formation, but they represent a necessary starting point for the future research program of the other 52 engine tests.

Only when the results of all 72 engine tests shall be disposable, we will have a complete picture of the investigated phenomenon.

THE RESEARCH PROGRAM

The research is an amplification of the research work on the same argument, supported by U.S. Department of the Army through its European Research Office under the contract DA-91-591-EUC-1661-OI-7321-61.

The present research work has the purpose to investigate on experimental basis the influence of some diesel fuels characteristics on the phenomenon of the deposits formation in high-speed diesel engines.

The characteristics, which have been investigated, are the following:

1) Specific gravity
2) Sulphur content
3) Cetane Number.

Twenty engine tests have been performed in the year covered by the present contract.

In the engine tests the running conditions and the test duration have been mantained constant, while the characteristics of the fuel, used in each engine test, have been varied, so that it has been possible to evaluate, through the deposits formed during and at the end of each test, the influence of the fuel characteristics on the amount of the deposits formed on some engine parts.

Since it could not be excluded that some particular fuel characteristics were able to carry severe deposits in running conditions different from those used in the standard test, eight of the twenty engine test have been performed following modified test conditions and using diesel fuels already tested in the standard conditions.

In this manner twelve of the engine tests have been performed following such running conditions that high temperatures of the cylinder head and of the cylinder walls could be reached, while the remaining eight tests have been run in such manner to have low temperatures of the mentioned engine parts.

For the above said reason twelve diesel fuels of diffe - rent characteristics have been prepared and tested.

These diesel fuels have been obtained following the scheme of preparation reported in table I.

In such manner it has been possible to have six samples of light gasoil - specific gravity = 0.823 - and six samples of heavy gasoil - specific gravity = 0.854.

The light and the heavy gasoils have been obtained from distillation of a commercial gasoil, - specific gravity = 0.835 - in an expressly designed and constructed distillation plant.

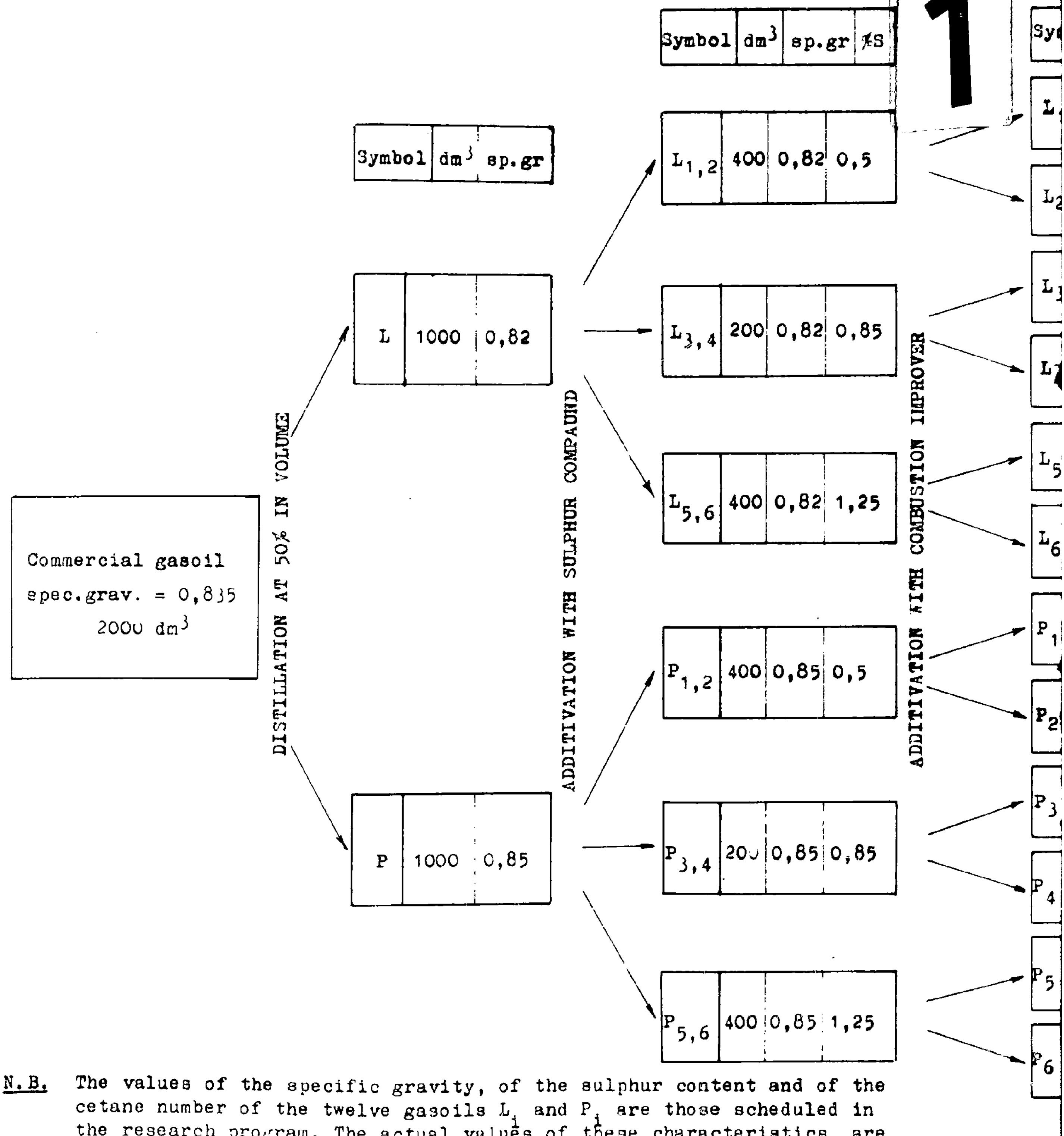
The scheduled values of the Sulphur Content and of the Cetane Number have been obtained by means of the additivation of a suitable sulphur compound and of a suitable combustion improver.

Since the sulphur content in the heavy distillated fraction (spec. gravity = 0.854) has resulted of 1.14%, we have tried the desulphurization of this fraction with the aim to obtain a heavy sample with lower sulphur content.

None of the simple procedures followed to desulphurize the heavy fraction has been successful.

For this reason we have resolved to perform the engine tests on the heavy gasoil with three sulphur contents (1.14% - 1.5% - 2.0%), different from those scheduled for light ga-

Table I: Scheme of the preparation of the 12 gasoil



N.B. The values of the specific gravity, of the sulphur content and of the cetane number of the twelve gasoils L_i and P_i are those scheduled in the research program. The actual values of these characteristics are reported in table III.

Table I: Scheme of the preparation of the 12 gasoil samples

gasoil
0,835
dm^3

DISTILLATION AT 50% IN VOLUME

Symbol	dm^3	sp.gr
L	1000	0,82
P	1000	0,85

2

ADDITIVATION WITH SULPHUR COMPAUND

Symbol	dm^3	sp.gr	%S
$L_{1,2}$	400	0,82	0,5
$L_{3,4}$	200	0,82	0,85
$L_{5,6}$	400	0,82	1,25
$P_{1,2}$	400	0,85	0,5
$P_{3,4}$	200	0,85	0,85
$P_{5,6}$	400	0,85	1,25

ADDITIVATION WITH COMBUSTION IMPROVER

Sym.	dm^3	sp.gr	%S	NC
L_1	200	0,82	0,5	45
L_2	200	0,82	0,5	55
L_3	100	0,82	0,85	45
L_4	100	0,82	0,85	55
L_5	200	0,82	1,25	45
L_6	200	0,82	1,25	55
P_1	200	0,85	0,5	45
P_2	200	0,85	0,5	55
P_3	100	0,85	0,85	45
P_4	100	0,85	0,85	55
P_5	200	0,85	1,25	45
P_6	200	0,85	1,25	55

ues of the specific gravity, of the sulphur content and of the
number of the twelve gasoils L_i and P_i are those scheduled in
earch program. The actual values of these characteristics are
d in table III.

TABLE I

soil (0.56% - 1.0% - 1.5%).

The sulphur compound, which has been added to the light and heavy fractions to obtain the above said sulphur contents, has been the carbon disulphide (CS_2).

To avoid the little variations of the Cetane Number of the gasoil samples, produced by the additivation of carbon disulphide, we have tried to obtain in the gasoil samples the three established sulphur contents by adding sulphur.

By means of laboratory tests have been determined the maximum sulphur contents obtainable in the light and in the heavy gasoils by dissolving sulphur in the gasoils at 150°C and by crystallizing the exceeding amount at 20°C.

In the table II we have reported the initial sulphur contents of the light and heavy fractions and the maximum sulphur contents obtained following the above said procedure.

Table II

Distillation fraction	LIGHT GASOIL		HEAVY GASOIL	
	As from distillation	After S additivation	As from distillation	After S additivation
Sulphur Content %	0,56	1,02	1,14	2.39

As through the sulphur additivation it has not been possible to rise the sulphur content of the light gasoil to the maximum value (1.5%) scheduled for the tests, the carbon disulphide has been used for additivation in all the samples, for uniformity.

It has been consequently necessary to determine on CFR engine the Cetane Number of all the gasoil samples.

These tests, performed following the Cetane Method ASTM-- D615, have emphasized that, with the used percentages, the influence of CS_2 on Cetane Number is very little.

The results of the CFR engine tests are summarized in Table III, where are reported the specific gravity, the sulphur content and the Cetane Number of the twelve gasoil samples.

In this table the light and the heavy gasoils are indicated by the symbols L and P respectively, while the ethyl nitrate is indicated by the symbol E.N.

As it results from Table III, the combustion improver added to the gasoil samples has been the ethyl nitrate. This compound has been selected out of three available combustion improvers: ethyl nitrate, diethyl ether and nitro benzene.

By means of C.F.R. engine tests, whose results are reported in Table IV, it has been emphasized that ethyl nitrate is the most efficient among the tested compounds, and that it is sufficient an additivation of 0,5% of this compound to obtain in the light and in the heavy samples an increase of the Cetane Number of about 15.

The ethyl nitrate has been added in all the samples, whose Cetane Number was to be increased, and the additivation percentage has been for all samples of 0,5%.

No mutual influence between ethyl nitrate and CS_2 in regard to the Cetane Number has been ascertained by means of the CFR engine tests, as it is well emphasized by the results reported in Table III.

TABLE III

GASOIL SYMBOL	GASOIL PROPERTIES		CETANE NUMBER		GASOIL SYMBOL	GASOIL PROPERTIES		CETANE NUMBER	
	Specific gravity	Sulphur Content%	Test results	Arithmetical mean		Specific gravity	Sulphur Content%	Test results	Arithmetical mean
L_1	0.823	0.56	54.2 54.0 54.1	54.1	P_1	0.854	1.14	55.1 54.7 54.9	54.9
L_2 $(=L_1+E.N)$	0.823	0.56	66.5 66.3 67.3	66.7	P_2 $(=P_1+E.N)$	0.854	1.14	70.1 69.7 69.9	69.9
L_3 $(=L_1+CS_2)$	0.823	1.14	54.2 55.0 55.5	54.9	P_3 $(=P_1+CS_2)$	0.854	1.50	55.9 56.4 55.7	56.0
L_4 $(=L_1+CS_2+E.N)$	0.823	1.14	67.1 67.3 67.2	67.2	P_4 $(=P_1+CS_2+E.N)$	0.854	1.50	71.0 71.5 71.4	71.3
L_5 $(=L_1+CS_2)$	0.823	1.50	55.5 55.4 55.6	55.5	P_5 $(=P_1+CS_2)$	0.854	2.00	56.4 56.7 57.0	56.7
L_6 $(=L_1+CS_2+E.N)$	0.823	1.50	67.8 67.6 68.0	67.8	P_6 $(=P_1+CS_2+E.N)$	0.854	2.00	72.0 72.5 73.0	72.5

Table IV

COMBUSTION IMPROVER	% BY VOLUME	GASOIL	
		L	P
Ethyl nitrate	0.00	54.2	54.9
	0.25	[illegible]	62.3
	0.50	66.7	69.9
	1.00	69.2	70.1
Diethyl ether	0.00	54.3	54.9
	0.25	54.5	55.0
	0.50	55.1	55.1
	1.00	55.2	55.2
Nitro benzene	0.50	54.3	54.9
	1.00	56.2	55.2
	1.50	56.3	55.5
	2.00	57.2	55.5

<u>THE TEST PLANT</u>

Two equal test plants have been used to perform the 20 engine tests of the research program.

The former was set up in the period (1st January 1961 - 30th June 1962), covered by the contract DA-91-591-EUC-1661-OI--7321-61.

The latter has been set up in the period covered by the present contract.

The test plants are formed by a Petter AV1 laboratory engine coupled to a generator.

The technical data of the Petter engine are:
Vertical engine, four stroke cycle, compression ignition, water cooled, cold starting;

Number of Cylinders	1
Bore	85 mm(3,15 in.)
Stroke	110 mm(4,33 in.)
Cubic Capacity	553 c.c.(33,73 cu.in.)
Compression Ratio	16,5:1
Rated Power and Speed	3 b.h.p.-1000 r.p.m.
	4 b.h.p.-1200 r.p.m.
	5 b.h.p.-1500 r.p.m.
	6 b.h.p.-1800 r.p.m.
Fuel Injection Timing	24° Before T.D.C.
Inlet Valve opens	4,5° Before T.D.C.
Inlet Valve closes	35,5° After B.D.C.
Exhaust Valve opens	35,5° Before B.D.C.
Fuel Pump	Bryce Type AIAA70/5SI52H
Nozzle	Bryce Type HLS26 C 175P3

Only one modification has been made on the engine: suppression of the governor and application, on the injection pump, of a micrometric system for fuel flow rate regulation.

As electric brake has been used a separately excited dynamo.

The test stand is composed by:

a) A cooling system formed by an external motor-driven pump and a surface cooler. A slide valve and a calibrated flange allow to settle and control the flow rate of the cooling liquid. The temperatures of the cooling liquid inlet and outlet are mesured

by two mercury thermometers.

b) A lubricating oil cooling system, external to the engine, composed by a motor driven pump and a surface cooler. Lubricating oil temperature in the crankcase is measured by a mercury thermometer.

c) A control board with excitation and load rheostats of the dynamo, with instruments for the control of the voltage, of the load current and of the excitation current, of the lubricating oil pressure, and with a tachymeter to control the angular speed of the engine.

d) A device to determine specific fuel consumption.

In fig. 1 is reported a scheme of the test plant.

THE STANDARD TEST CONDITIONS

Selected on the basis of the results obtained during the research work of the contract DA-91-591-EUC-1661-OI-7321-61, the standard test conditions followed to perform the engine tests have been the following:

- R.p.m. .... 1500 ± 50
- Consumption time for 100 grams of gasoil ... 193 ± 3 sec
- Crankcase oil temperature .... 55°C
- Oil pressure .... 0,5 kg/sq. cm

For the twelve engine tests, performed using kerosene as coolant, the flow-rate and the temperatures of the coolant have been:

Kerosene flow rate .... 1020 l/h

Kerosene temperatures .... inlet = 79 °C

outlet = 85 °C

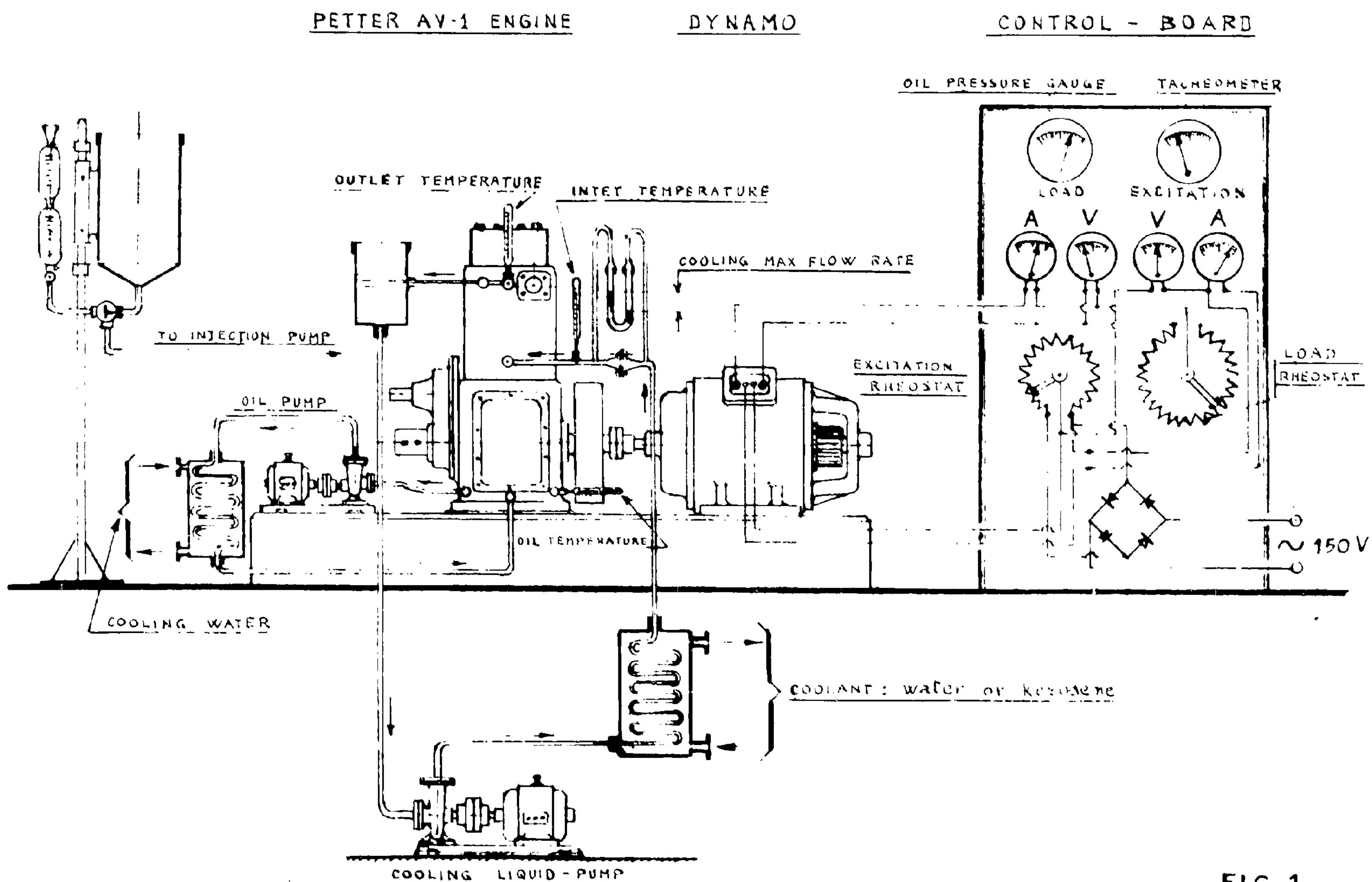

PETTER AV-1 ENGINE
DYNAMO
CONTROL - BOARD
OIL PRESSURE GAUGE
TACHEOMETER
LOAD
EXCITATION
A
V
V
A
OUTLET TEMPERATURE
INLET TEMPERATURE
COOLING MAX FLOW RATE
TO INJECTION PUMP
OIL PUMP
EXCITATION RHEOSTAT
LOAD RHEOSTAT
OIL TEMPERATURE
~ 150 V
COOLING WATER
COOLANT : water or kerosene
COOLING LIQUID - PUMP

FIG. 1

For the eight engine tests, performed using water as coolant, the corresponding values have been:

Water flow rate .... 1020 l/h

Water temperatures .... inlet = 47 °C

outlet = 50 °C

Each engine test has had a complete duration of 36 hours and has been performed in six periods, each of six hours.

At the beginning of each test, the engine has been completely overhauled and a new piston and a new injector-nozzle have been mounted.

In appendix 1 is reported a synthesis of the operations for the engine preparation before starting each test.

THE METHOD OF EVALUATION OF THE AMOUNT OF THE DEPOSITS.

The analysis of the deposits formed during and at the end of the 36 hours of engine test has been limited to the piston crown and to the injector-nozzle.

This limitation has been adopted for practical purposes. In reality the analysis had to be made on those engine members, which may be reached from the fuel or from the combustion products. Some of these members, as e.g. the cylinder head, have a geometry not suitable for qualitative or quantitative analysis of the deposits formed on them, so that the same analysis has been limited to those members (piston crown and injector nozzle) which, for their geometry, are particularly easy to be analyzed and, for the consequences which the deposits formed on them may have on the engine working conditions, can be retained representative of the phenomenon.

To evaluate the quantity of the deposits on the needle, on the needle seat and along the spray hole of the injector-nozzle the same injector-nozzle has been, at the end of the engine tests, cut with care on a grinding machine.

The photography of one of the cut nozzles is reported in fig. 2.

In this manner it has been possible to photograph at the microscope the needle seat and the spray hole.

In fig. 3 is reported the microphotography of the above said zone of the injector-nozzle of the engine test n. 20.

For the same test in fig. 4 is reported the photography of the injector needle.

The parts represented in fig. 3 and fig. 4 are magnified 12.5 times.

The evaluation of the deposits formed on the piston crown has been made by means of a transparent mask in plexiglass, divided in 25 parts, which can be adapted to the piston crown.

A merit equal 0 has been assigned to each part completely blackened by deposits, and a merit equal 1 to each part free from deposits.

Intermediate merits are assigned to the parts only partially covered by deposits. Summing all the merits of each surface element gives a percent evaluation of the deposits on the piston crown, in the ring grooves and on the piston lands.

The evaluation is performed by reporting on the table of fig. 5 the relative merits of each elementary part.

The merit ratings of the above said zone of the piston have been assigned at the end of each period of six hours of the

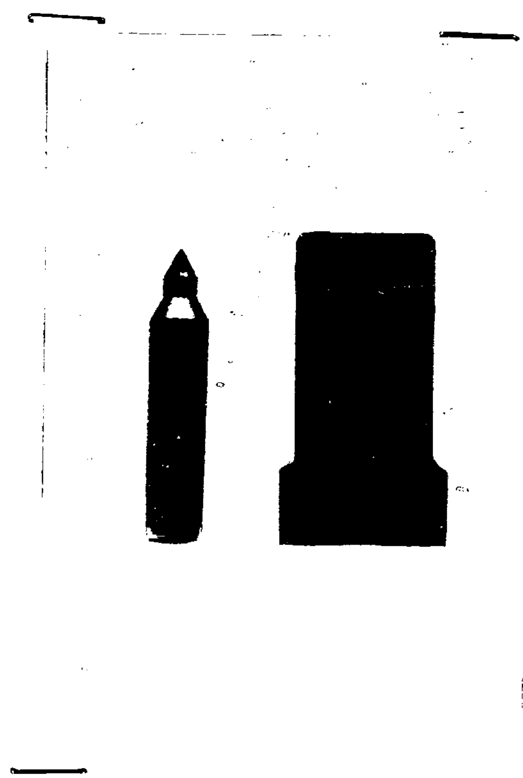


FIG. 2

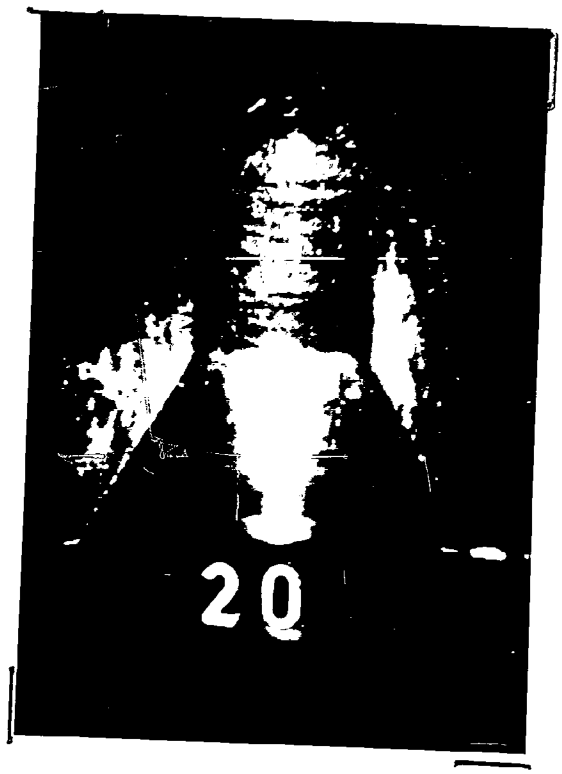


FIG. 3

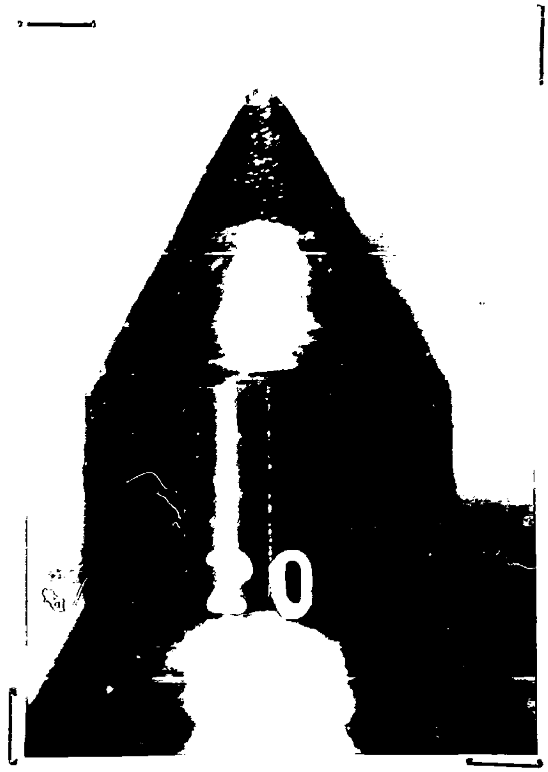
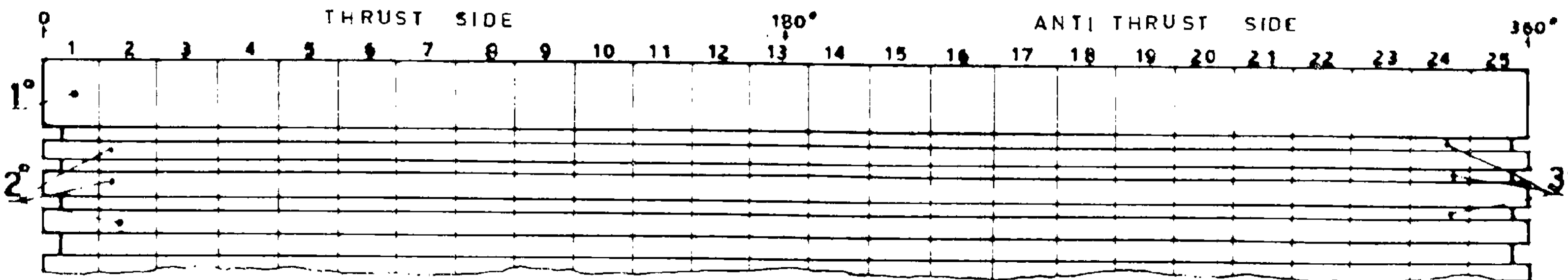


FIG. 4



DEPOSITS	ZONE		ELEMENTARY ZONE 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
LACQUER DEPOSITS	1° CROWN																										
LACQUER DEPOSITS	2° PISTON LAND	I																									
		II																									
		III																									
LACQUER DEPOSITS	3° RING GROOVE	I																									
		II																									
		III																									

1° - Piston crown
2° - Piston lands (average)
3° - Ring grooves (average)

FIG. 5

engine test. For this reason it has been necessary to dismount the engine head and the piston six times during each test.

The evaluation procedure appears more clearly from the table. This evaluation, in spite of its subjective basis, has been tested satisfactorily repeatible and reproducible.

To obtain (at the end of the engine test) a photographic record of the piston has been used a photographic system which permits to obtain a developed surface of the piston crown.

THE ENGINE TEST RESULTS

The results of the twenty engine tests have been reported on the attached diagrams.

In each diagram are plotted, versus test hours, the merit ratings, obtained by means of the described procedure, of the piston crown, of the piston lands and of the ring grooves.

From these diagrams some general considerations can be made:

1°) In all engine tests, excepting the test No. 4, the deposits are formed in relatively larger amount on the zones closest to the combustion chamber.
In regard to this phenomenon it may be noted that each of the three ring grooves is closer to the combustion chamber than each corresponding piston land.
For the above said reasons the curves of the merit ratings of the piston lands are higher than the corresponding curves of the ring grooves merits, and these are higher than those of the merits of the piston crown.

Exceptionally for the test No. 4 the curve relative to the piston crown is higher than the one relative to the ring grooves.

2°) During the tests the increase of the deposits in the ring grooves and on the piston lands has been generally continuous; while for the piston crown deposits an initial steep increase in the first test hours is sometime followed in the successive test periods by a slight decrease (see e.g. the diagrams of tests No. 7-9-10-17).
This phenomenon may be explained as follows.
An initial steep increase of the deposits on the piston crown results in a steep initial increase of the deposit thickness, until the formed deposit coat fills the clearance between piston crown and cylinder walls.
Due to the periodic reversals of the side thrust and of the consequent movement of the piston normally to the cylinder axis, the above said deposit coat tends to be detached from the piston crown and the detached matherials act as an abrasive on the deposits which still adhere.
This mechanism explains the observed decrease of the coated surface on the crown and the appearance of more or less deep scratchings on the deposit coating of the crown.
As a consequence of these phenomena the percentage of the piston crown surface coated by deposits cannot be assumed as representative of the amount of the deposits formed on the same zone; and no other rating criterion can be conveniently adoped in substitution of that grounded on the percentage of the coated surface. In fact the other rating parameter - deposit thickness - tends to a limit, which, as the preceeding

considerations have proved, could be already reached after the first test hours.

In other word: if during the test the deposits formed on the piston crown become detached - as experimentally observed - this detachement takes place because the deposit coat has reached on some crown parts a thickness such as to bring the coating in contact with the cylinder walls; from this point on, the deposits on the crown cannot further increase on the considered zones, while it is possible that they decrease in consequence of the detachement of part of them.

As consequence, neither the coated surface nor the deposit thichness can be assumed separately or together as rating elements for the evaluation of the deposits amount formed on this zone.

For this reason, analyzing the test results, it has not been judged convenient to calculate, for each test, the average of the merit ratings relative to the three examined zones of the piston, as the piston crown merit ratings are not as much reliable as the merit ratings relative to the ring grooves and to the piston lands.

From what has been said it results that to give a correct consideration to the deposits formed on the three examined zones of the piston, it would be necessary to assign a different weight factor to each of the corresponding merit ratings.

The said weight factor would be equal 1 for the merit ratings of the ring grooves and would assume a value inferior to 1 for the merit ratings of the piston lands and yet lower value for the merit ratings of the piston crown.

It is worth to emphasize that this criterium would give a higher importance to the deposits in the ring grooves, whose amount not only gives a more reliable misure of the deposits formed on the piston, but also has the heaviest weight in regard to the consequences of the phenomenon of the deposit formation. In fact the deposits formed in the ring grooves are responsible for ring sticking and for the well known disadvantageous effects deriving from it: decrease of compression pressure, combustion gases leakage to the carter, etc.

Although the opportunity to introduce weight factors for the merit ratings has been recognized and although the succession of their values has been ascertained, actually we have not sufficient data to assign concrete values to the said factors.

A more detailed analysis on this point shall made during the more extensive research work programmed for the next year. Actually the obtained results may be valuated taking in account exclusively the merit ratings of the ring grooves.

In the fig. 6, 7 and 8 are plotted the final values of the merit curves relative to the ring grooves, representing final merits obtained taking in account the behaviour of the phenomenon during the entire test.

To emphasize the influence of the gasoil's specific gravity on the amount of the formed deposits, in fig. 6 are reported the above said final merits relative to the test couples, each of which is characterized by the same values of the cetane number and of the sulphur content and by different values of the specific gravity.

For the small amount of the results obtained and because the test No. 3 (gasoil L_3 - Coolant = Kerosene) has to be conside-

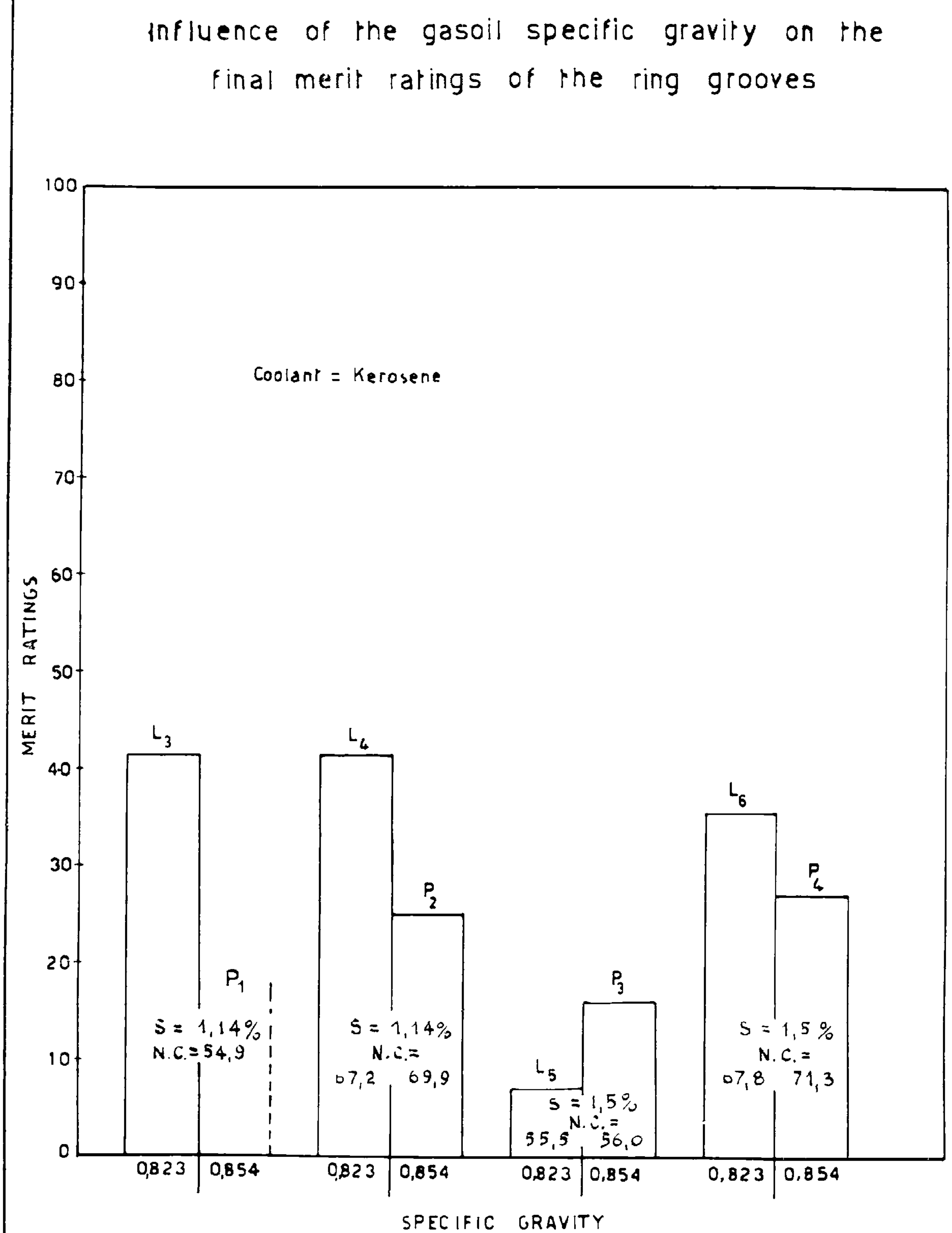

Influence of the gasoil specific gravity on the
final merit ratings of the ring grooves
Coolant = Kerosene
MERIT RATINGS
100
90
80
70
60
50
40
30
20
10
0
L3
P1
S = 1,14%
N.C.=54,9
L4
P2
S = 1,14%
N.C.=
67,2 69,9
L5
P3
S = 1,5%
N.C.=
55,5 56,0
L6
P4
S = 1,5 %
N.C. =
67,8 71,3
0,823
0,854
SPECIFIC GRAVITY

FIG.6

Influence of the sulphur content on the final merit ratings of the ring grooves

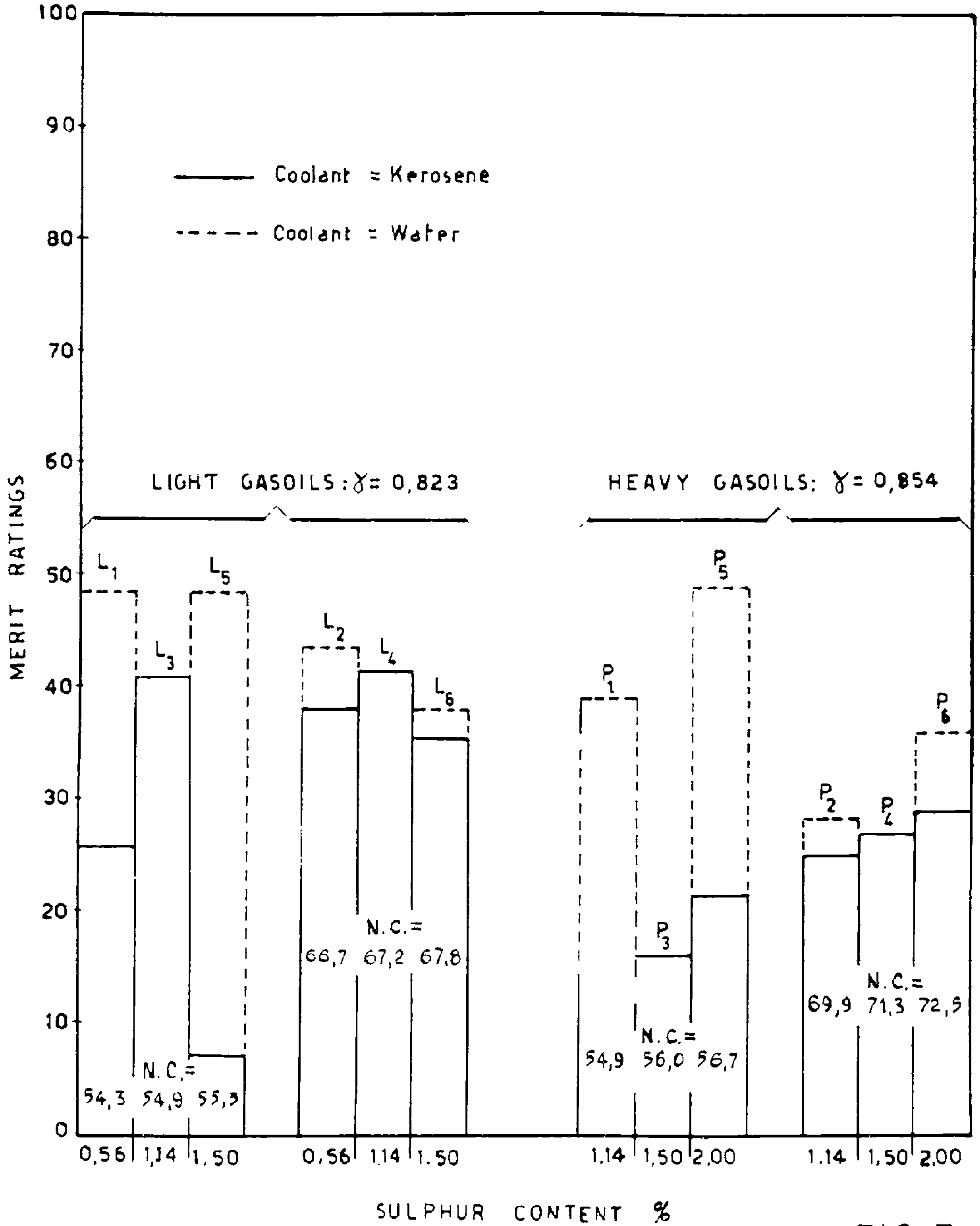


FIG. 7

Influence of the cetane number on the final merit ratings of the ring grooves

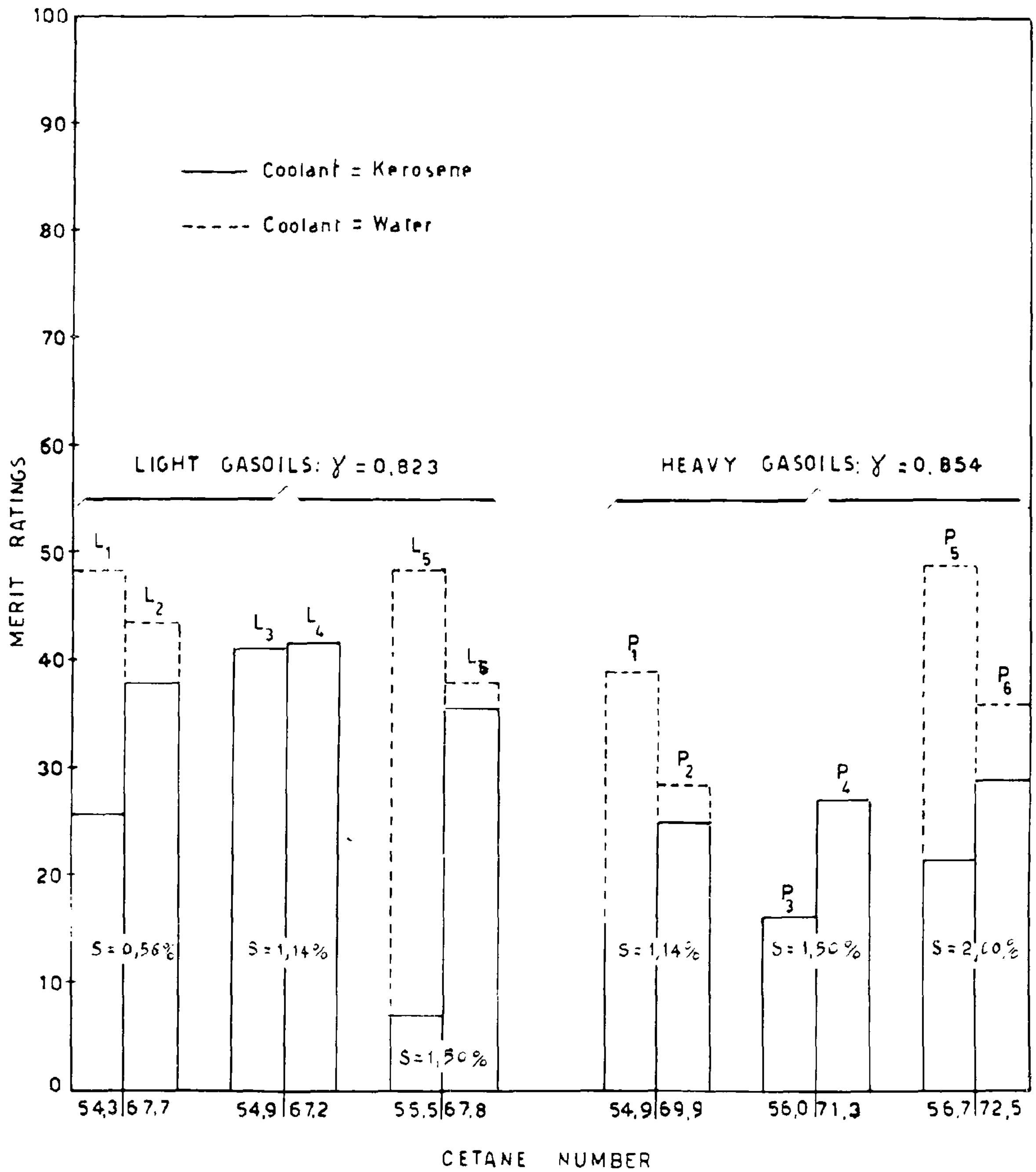


FIG.8

red unreliable, it is not possible to conclude for what concerns the influence of the specific gravity on the phenomenon of the deposit formation.

Out of the three reliable results (test couples on gasoils L_4-P_2, L_5-P_3, L_6-P_4) two (L_4-P_2 and L_6-P_4) show an increase of the amount of the deposits for increasing density of gasoil, whereas the third result (L_5-P_3) shows an opposite behaviour.

For what concerns the influence of the sulphur content from fig. 7 it appears:

1) In light gasoils the increase of the sulphur content has been not always accompanied by an increase of deposits. This inconstant behaviour has been observed in the tests run using kerosene as coolant (high temperature of cylinder walls), as well as in few tests repeated using water as coolant (low temperature of cylinder walls).
2) For what concerns the heavy gasoils, the obtained results show a decrease of deposits with increase of the sulphur content: this behaviour is common to the tests run with kerosene or water as coolants.

The influence of the cetane number on the amount of deposits may be deduced from fig. 8, in which have been coupled the final merit ratings of the ring grooves relative to the tests run on gasoils having the same specific gravity, the same sulphur content and different values of the cetane number.

From the figure it appears that:

1) For all the couples of gasoils, tested using kerosene as coolant, for both light and heavy gasoils, the increase of cetane number has brought always to a decrease of the formed deposits.

2) Apposite results show the eight tests performed using water as coolant.

From fig. 7 and 8 it results also that in all tests performed using water as coolant (low temperature of the cylinder walls) the amount of the formed deposits has been less than the amount observed in the corresponding tests performed using kerosene as coolant (high temperature of the cylinder walls).

For what concerns the deposits on the needle seat, on the spray hole and on the needle end of the atomizer, the attached 40 photographs show, for each of the 20 performed engine tests, the above said zones of the atomizer magnified 12.5 times.

Each couple of photographs is marked with the test number. To make easy the comparison of the said photographs, each couple has been also marked with the gasoils symbol (L_i or P_i) and with the symbols K (kerosene) or W (water), indicating the cooling fluid.

From the comparison of the photographs related to test couples performed with gasoils having different specific gravity and the same other characteristics (see photographs of the tests couples: 3-L_3-K and 2-P_1-K; 12-L_4-K and 14-P_2-K; 4-L_5-K and 5-P_3-K; 13-L_6-K and 15-P_4-K) it appears, on an average, a major amount of deposits in the tests performed on the heavy gasoils.

These deposits have been formed in great amount in the little chamber downstream the needle seat and upstream the spray hole: this results is due to the fact that the velocity of the gasoil during injection is lower in the above said chamber than in the other zones of the atomizer, and that the same chamber may be reached from the combustion products at the beginning of the expansion stroke.

For what regards the influence of the sulphur content of the

gasoil, comparing the photographs corresponding to the gasoil ternes which appear in the fig. 7, it results that the deposits, on all the examined zones of the atomizer, increase when sulphur content increases, for both coolants , kerosene and water.

As far as the influence of the cetane number is concerned, comparing the photographs corresponding to the gasoil couples, which appear in the fig. 8, it results that:

a) When kerosene has been used as coolant it may be noted an increase of the deposits in the tests performed on high cetane number gasoils, indipendently if heavy or light.

b) When water has been used as coolant, opposite results are observed.

As for the deposits in the ring grooves, also for the deposits formed inside the atomizer the influence of the gasoil's cetane number has been different according to the circustance that the engine temperature was high or low; but in this case the influence of the temperature appears to have been opposite.

So, while with high temperatures of the cylinder walls and head to an increase of the cetane number corresponds a lower amount of deposits in the ring grooves and a higher amount in the atomizer, with low temperature of the cylinder walls and head to an increase of the cetane number corresponds an increase of deposit in the ring grooves and a decrease inside the atomizer.

CONCLUSIONS

The analysis of the results of the 20 engine tests has emphasized some aspects of the phenomenon which, because of their singularity, need to be confirmed by the engine tests programmed in the next year.

These aspects of the phenomenon are:

1) The influence of gasoil sulphur content on the amount of the deposits on the piston seems to be different for light and heavy gasoils.
2) The action of the combustion improver, added to the gasoil, seems to have different effects on the amount of the deposits, according to the temperature of the cylinder walls and of the cylinder head: at the high temperatures the combustion improver seems to produce a decrease of the deposit amount, while at the low temperatures by adding the combustion improver has been noted an increase of the deposits on the piston.
3) Also on the deposits formed in the injector nozzle the gasoils cetane number seems to have different effect, according to the different cooling conditions. But by increasing the cetane number the influence of the cooling conditions is such to produce more severe deposits in the injector nozzle when the deposits on the piston result relatively less severe.

Besides these singular aspects of the phenomenon the engine tests have emphasized some other general aspects:

a) The amount of the deposits on the piston and inside the injector nozzle increases when the engine cooling allows the increase of the temperature of the cylinder walls and of the engine head.
b) The deposits are formed in larger extent on the piston zones closest to the combustion chamber.
c) The deposits, which are formed on the piston crown and on the piston lands, may be detached during the engine running, so that the piling up of the deposits during the test is not continuous.

Because of this phenomenon the final merit ratings of these zones of the piston have a different reliability respect to the merit ratings of the ring grooves, so as for a correct total merit evaluation of the piston the introduction of opportune weight factors is requested.

d) The deposits, which are formed on the needle end and on the parts of the injector nozzle downstream the needle seat, show such an appearance to support the opinion that the combustion products may enter into the nozzle during the expansion stroke through the injector hole.

Naples, 31 July 1963

STATEMENT OF THE AMOUNT OF THE EXPENSES SUBSTAINED IN THE PERIOD
1st MAY - 31th JULY 1963

1) N° 8 partial revisions of the Petter AV1 engine (8 x 40.000)	....	£	320.000
2) N° 1 complete revision of the Petter AV1-plant	....	"	500.000
3) Photographic material	....	"	50.000
4) Personnel:			
a) Research director (3 x 50.000)	....	"	150.000
b) 1 Half-time engineer (3 x 70.000)	....	"	210.000
c) 2 Half-time technicians (2 x 3 x 40.000)	....	"	240.000
d) 2 Half-time workers (2 x 3 x 35.000)	....	"	210.000
		£	1.680.000

Residual expenses from precedent reports: £ 65.000

Total expenses (1.680.000 + 65.000) = £ 1.745.000

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APPENDIX 1

Engine preparation

1°) Cleaning with kerosene of the parts of the engine and of the lubricating oil circuit.

2°) Control of the following parts of the engine:

a) Liner: clearance between liner and piston, measured across two diameters at right angles, in three axial positions, less than 0,08 mm; ovality less than 0,04 mm.

b) Cylinder head: decarbonize; grind the valves in the seats; valve pocketing less than 1,25 mm.

c) Cylinder: control the clearance between the piston and the cylinder head at T.D.C. (bumping clearance), This clearance must be to 0.9 to 1.0 mm, otherwise replace the shims between the cylinder block and the crankcase.

d) Crankshaft: after twenty tests control the ovality of the main journals and of the crankpin: maximum ovality must not exceed 0,08 mm; if exceeding reground. Control the main journals coaxiality: it must be less than 0.03 mm.

e) Main bearings: examine at each 10 tests group and replace if scraped or bedded in, or if crankshaft has been regrounded.

f) Connecting road: replace the small end bush, if clearance between bush and pin exceeds 0.02 mm. Replace at each 5 tests the big end bearing shells. Control connexting rod aligment.

g) Injector: replace the injector and control the release pressure (165 ÷ 185 kg/sq. cm) and the time necessary for the

pressure to decrease from the release pressure to a pres sure of 70 kg/sq. cm: this time must not be less than 15".

h) Fuel pump: control injection timing (24° B.T.D.C.)

i) Timing system: control the timing system and the valves clearances (0.18 mm).

3°) Piston Replacement: fit the new piston after the following controls:

α) Axial height of the grooves measured with feelers.

β) Rings height.

γ) Ring side clearance: lap the rings to obtain a clearance of 0.05 mm for the compression rings and of 0.075 mm for the scraper ring.

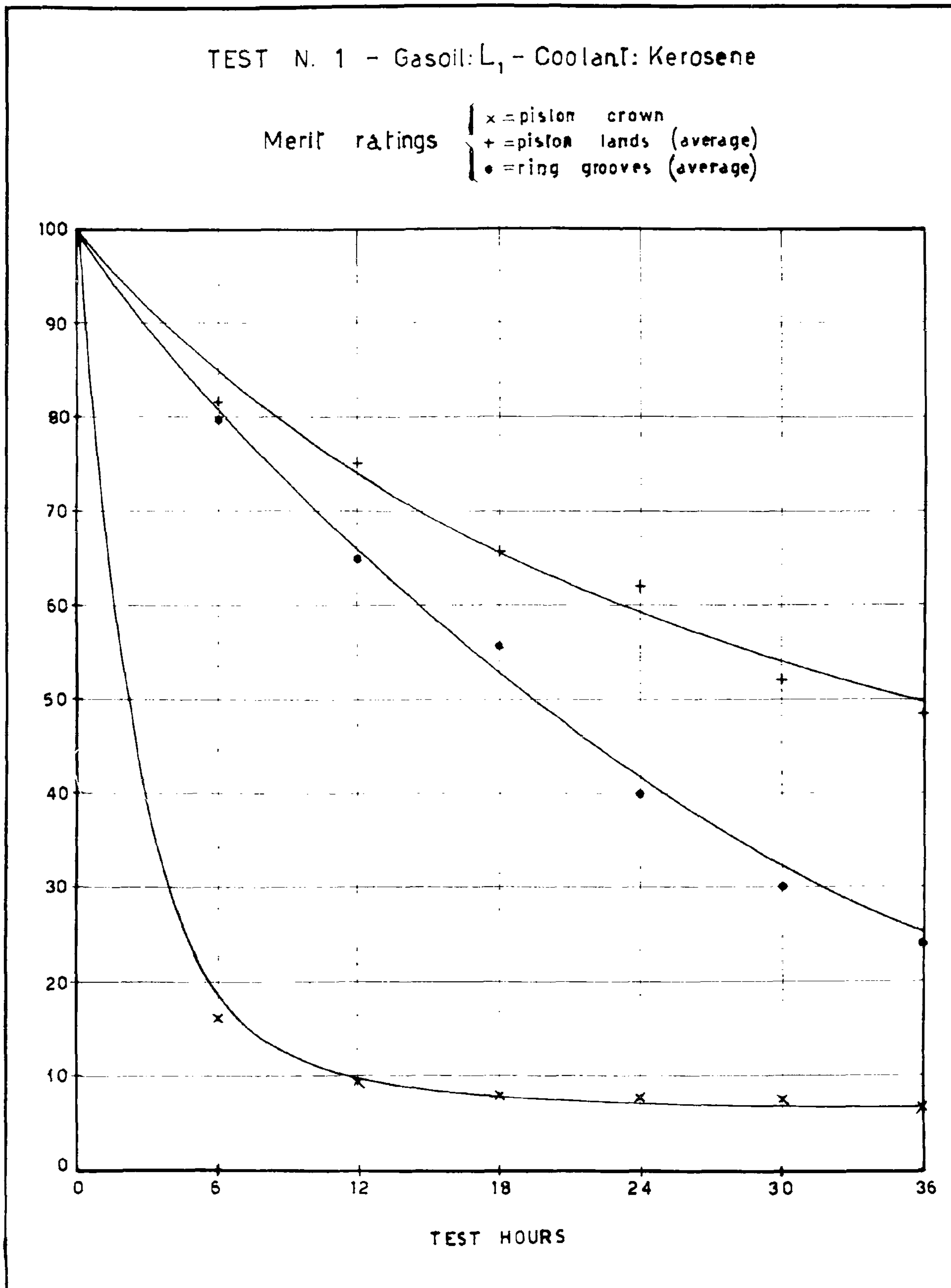
δ) Set the top compression and scraper ring gaps at 0.35-0.40 mm in a jig, eventually by lapping on the periphery.

4°) Charge of lubricating oil: 3,5 litres to fill the crankcase and the lubricating oil circuit.

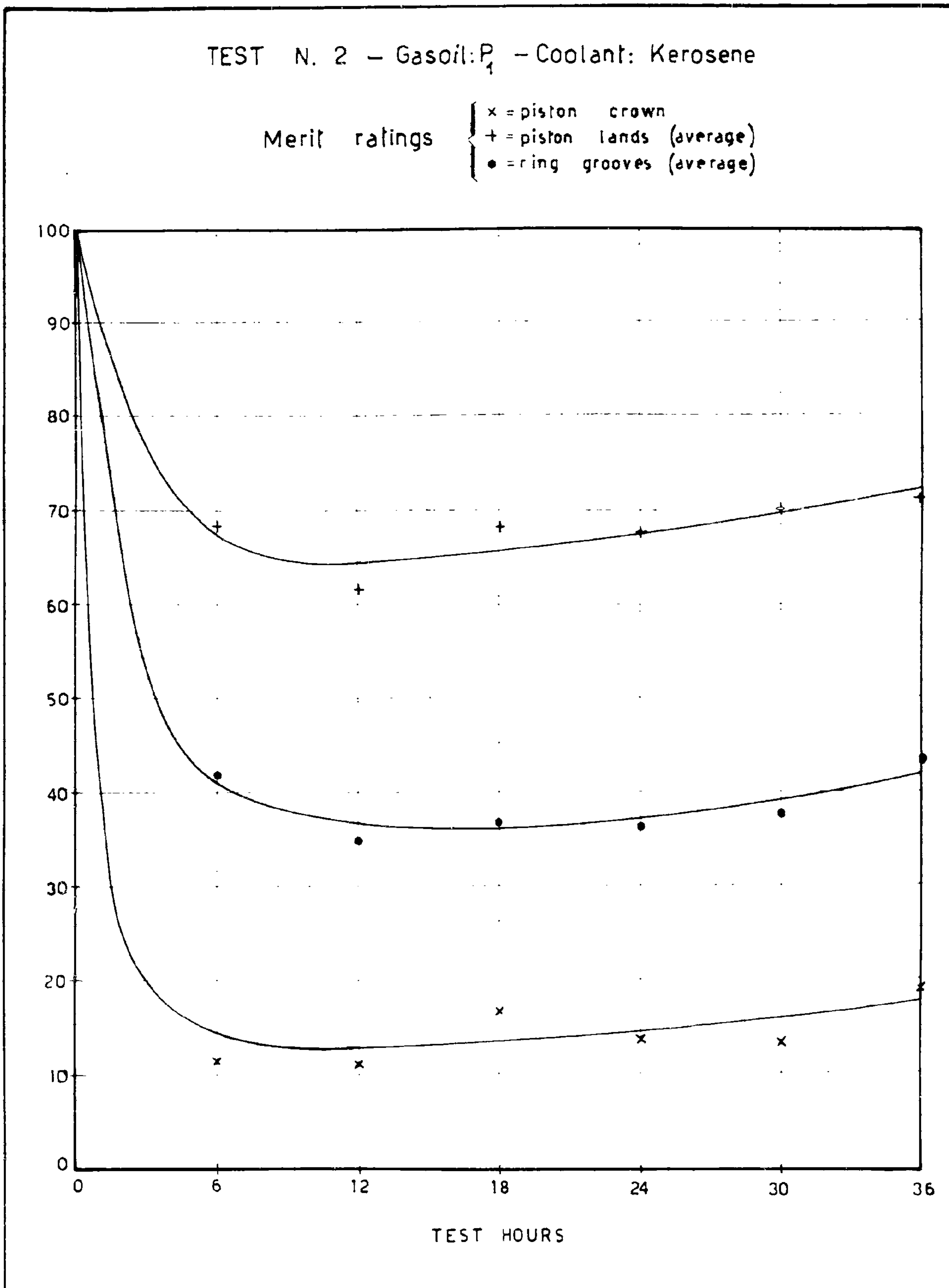
5°) Charge of cooling liquid.

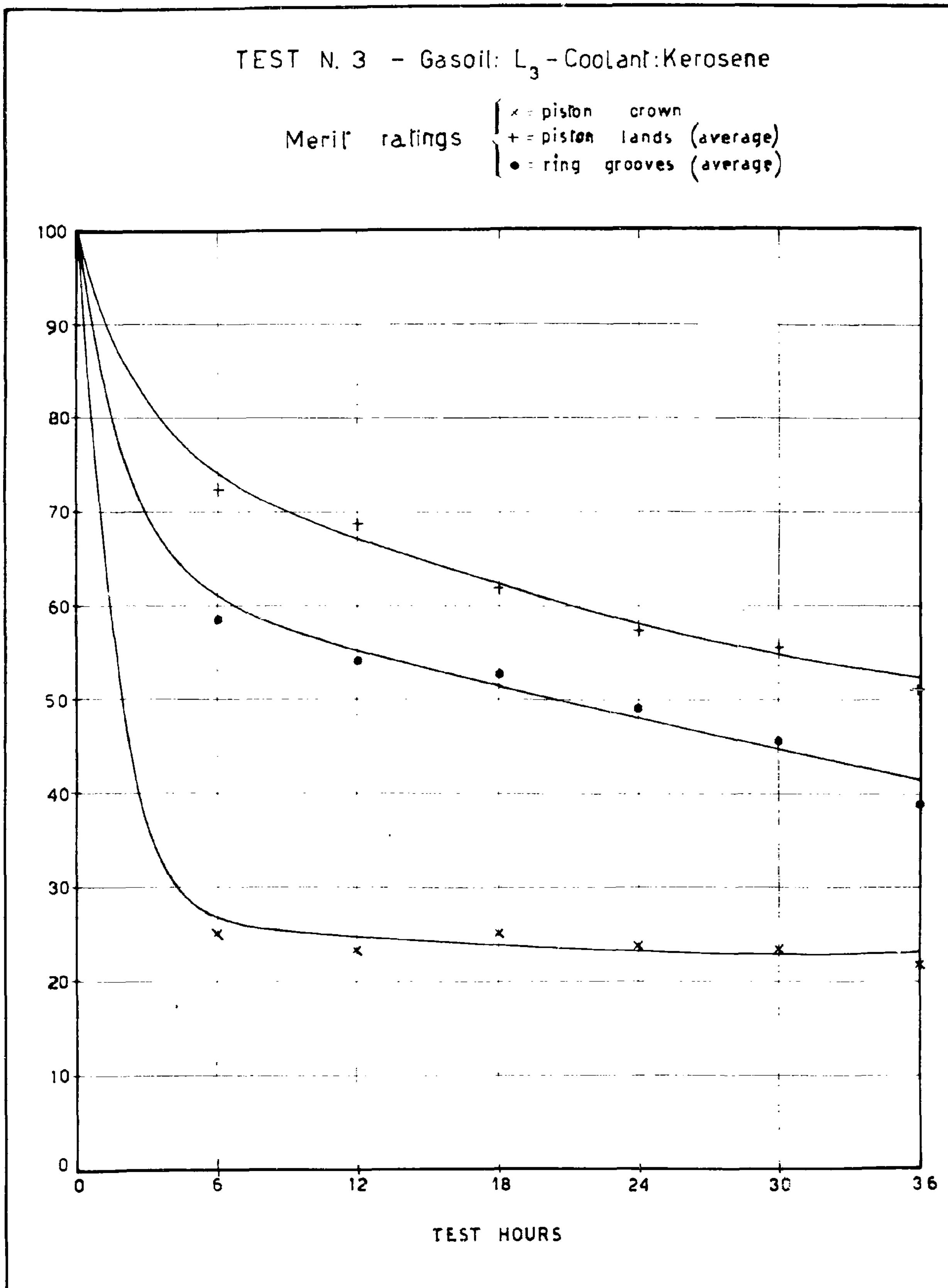
6°) Control the flow rate of the injection pump: set the position of the pump rack so that the delivery time for 100 grams of gasoil at 1500 r.p.m. is 193 ± 3 sec.

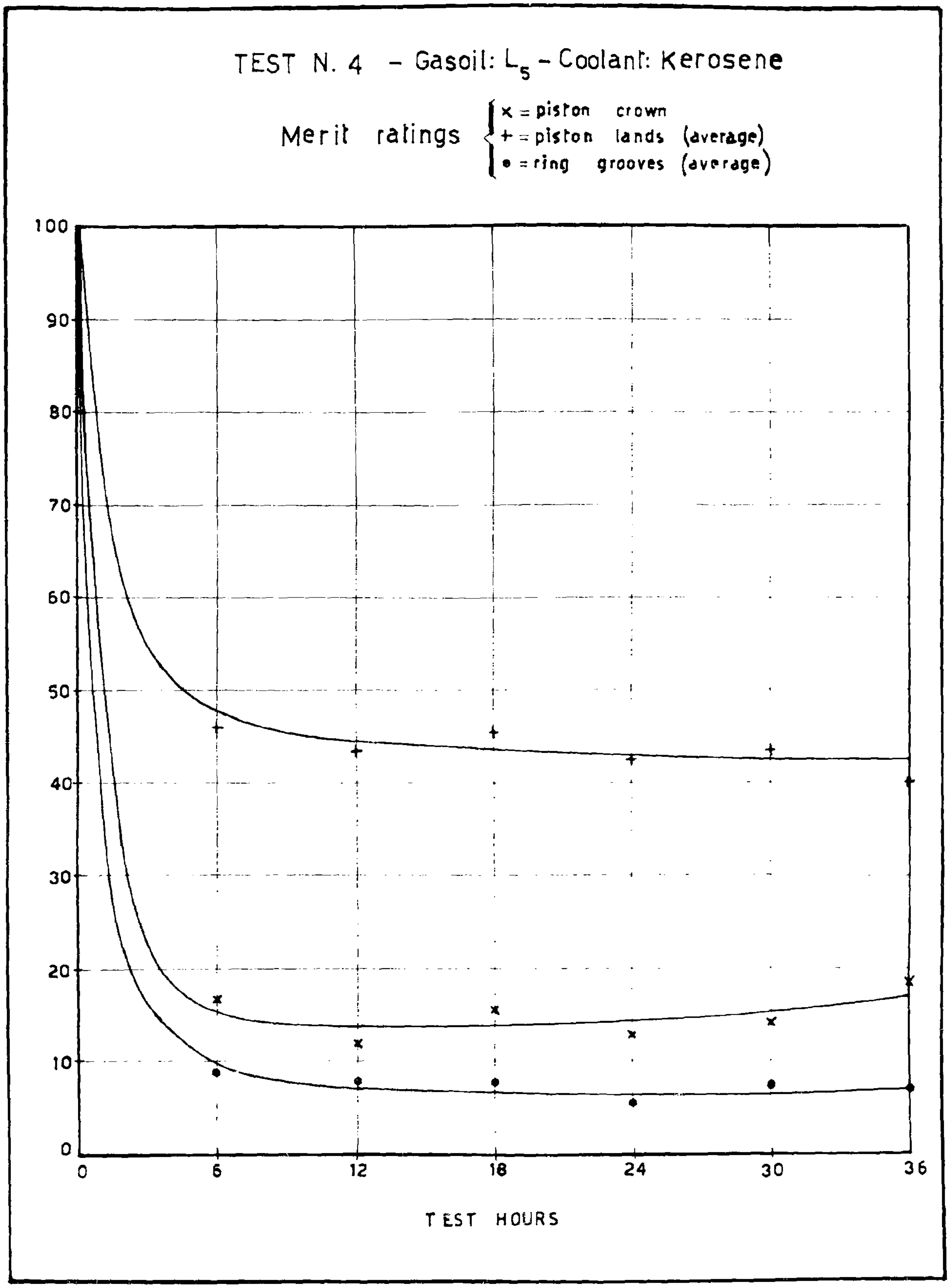
7°) Control the flow rate of cooling liquid.

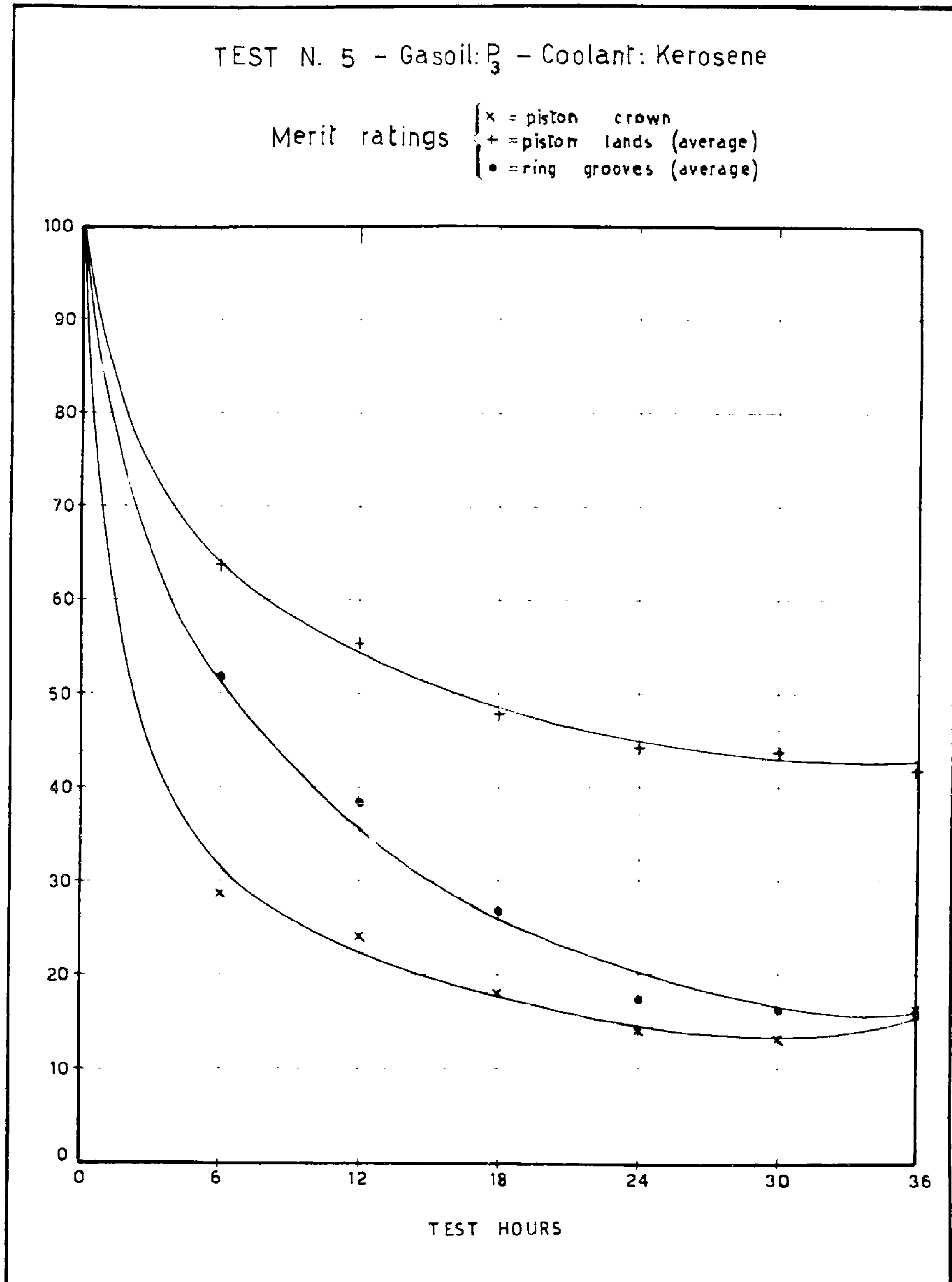


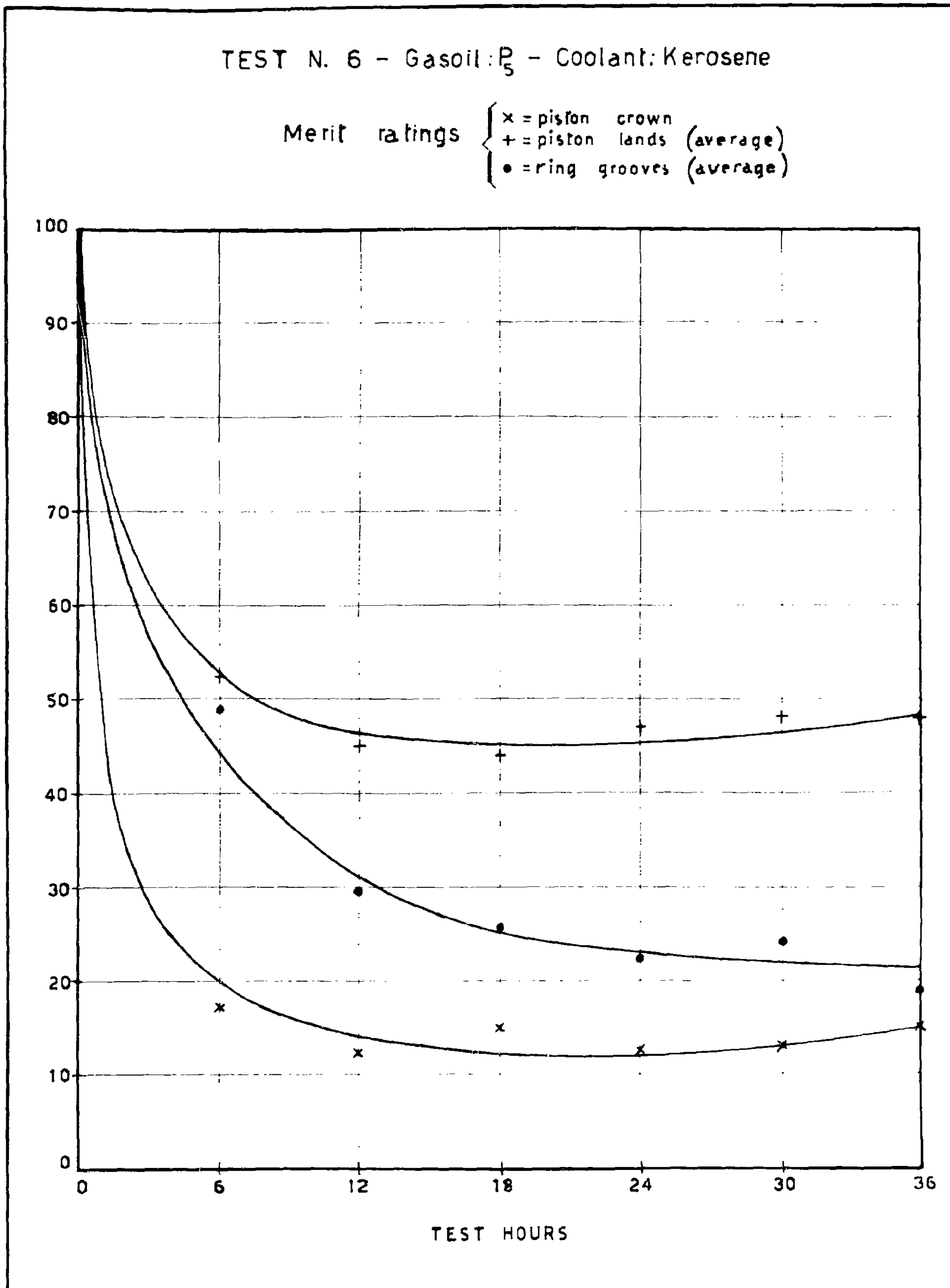
TEST N. 1 - Gasoil: L1 - Coolant: Kerosene
Merit ratings
x = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

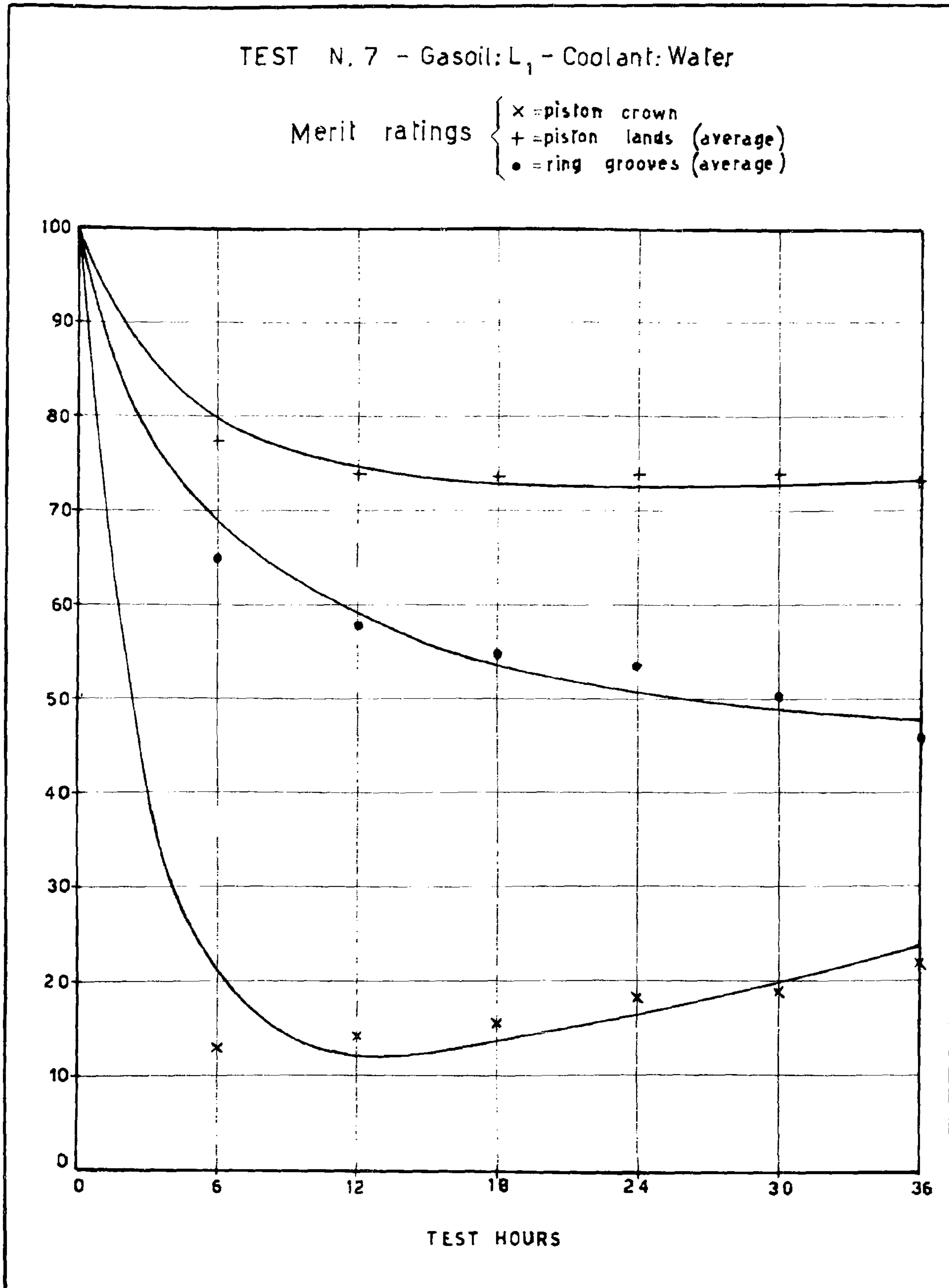

TEST N. 2 – Gasoil: P_1 – Coolant: Kerosene
Merit ratings
× = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

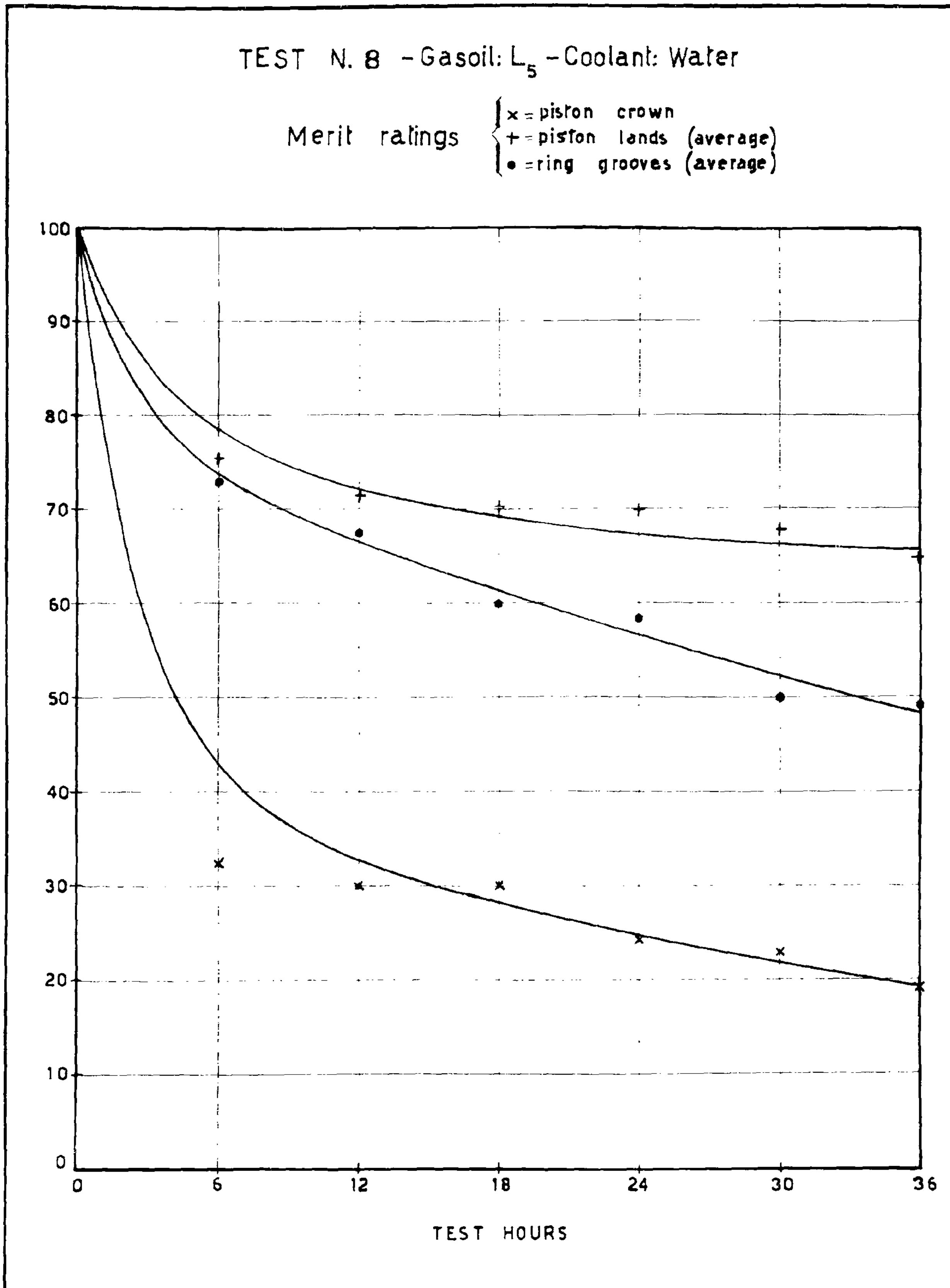

TEST N. 3 - Gasoil: L_3 - Coolant: Kerosene
Merit ratings
x = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

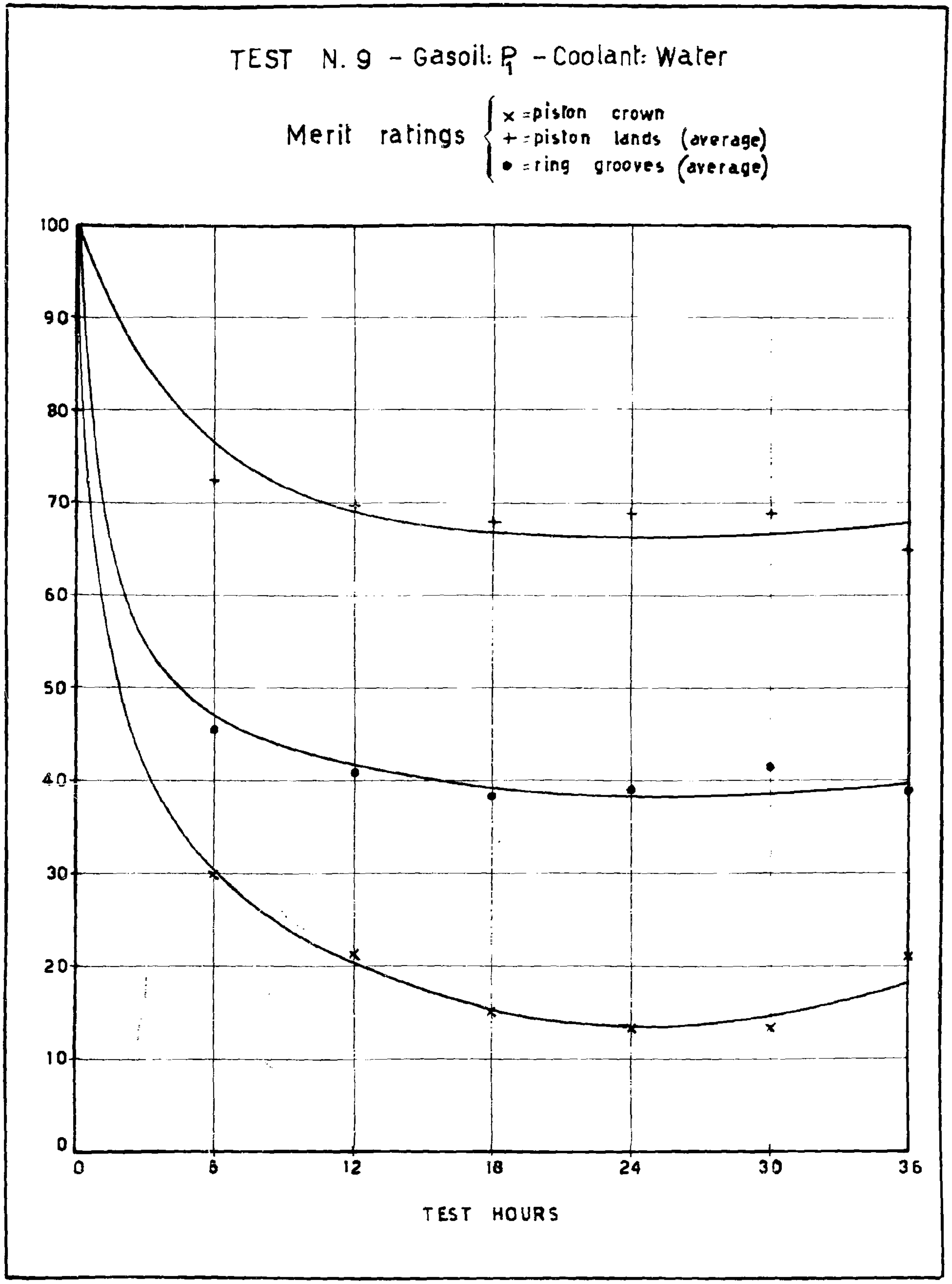

TEST N. 4 – Gasoil: L_5 – Coolant: Kerosene
Merit ratings
× = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS


TEST N. 5 - Gasoil: P_3 - Coolant: Kerosene
Merit ratings
× = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

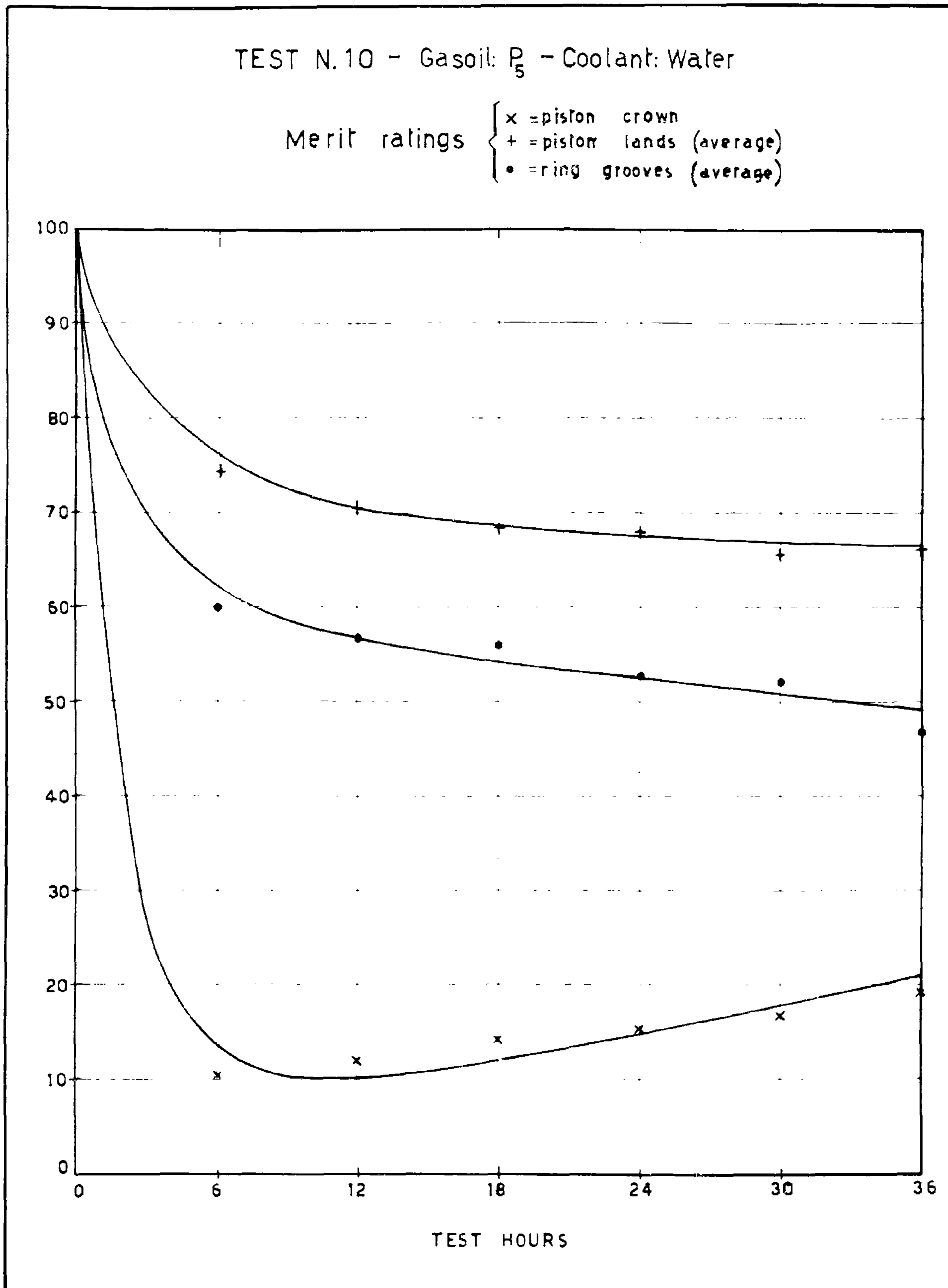

TEST N. 6 - Gasoil: P_5 - Coolant: Kerosene
Merit ratings
× = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS


TEST N. 7 - Gasoil: L_1 - Coolant: Water
Merit ratings
× = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

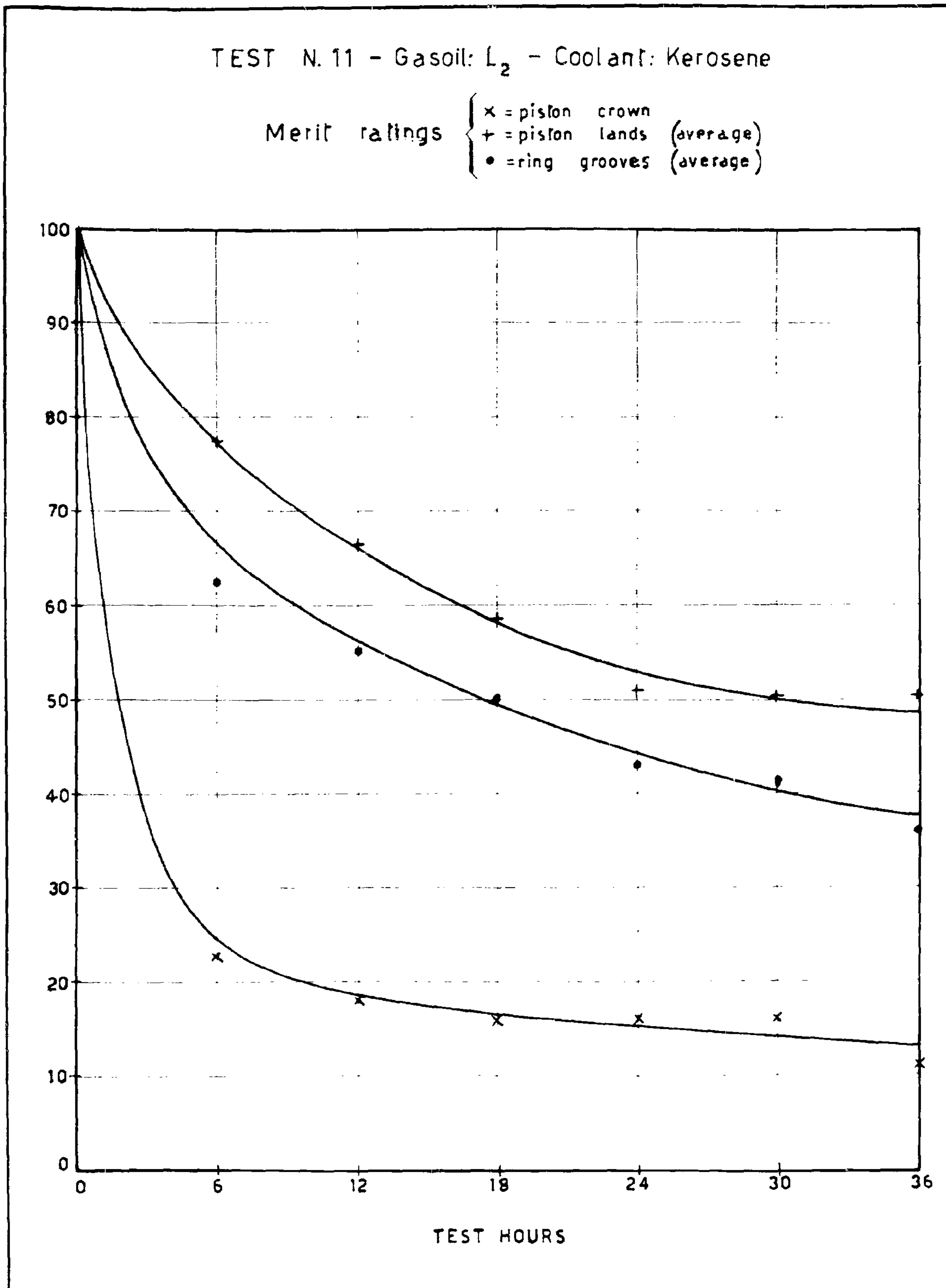

TEST N. 8 - Gasoil: L_5 - Coolant: Water
Merit ratings
x = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

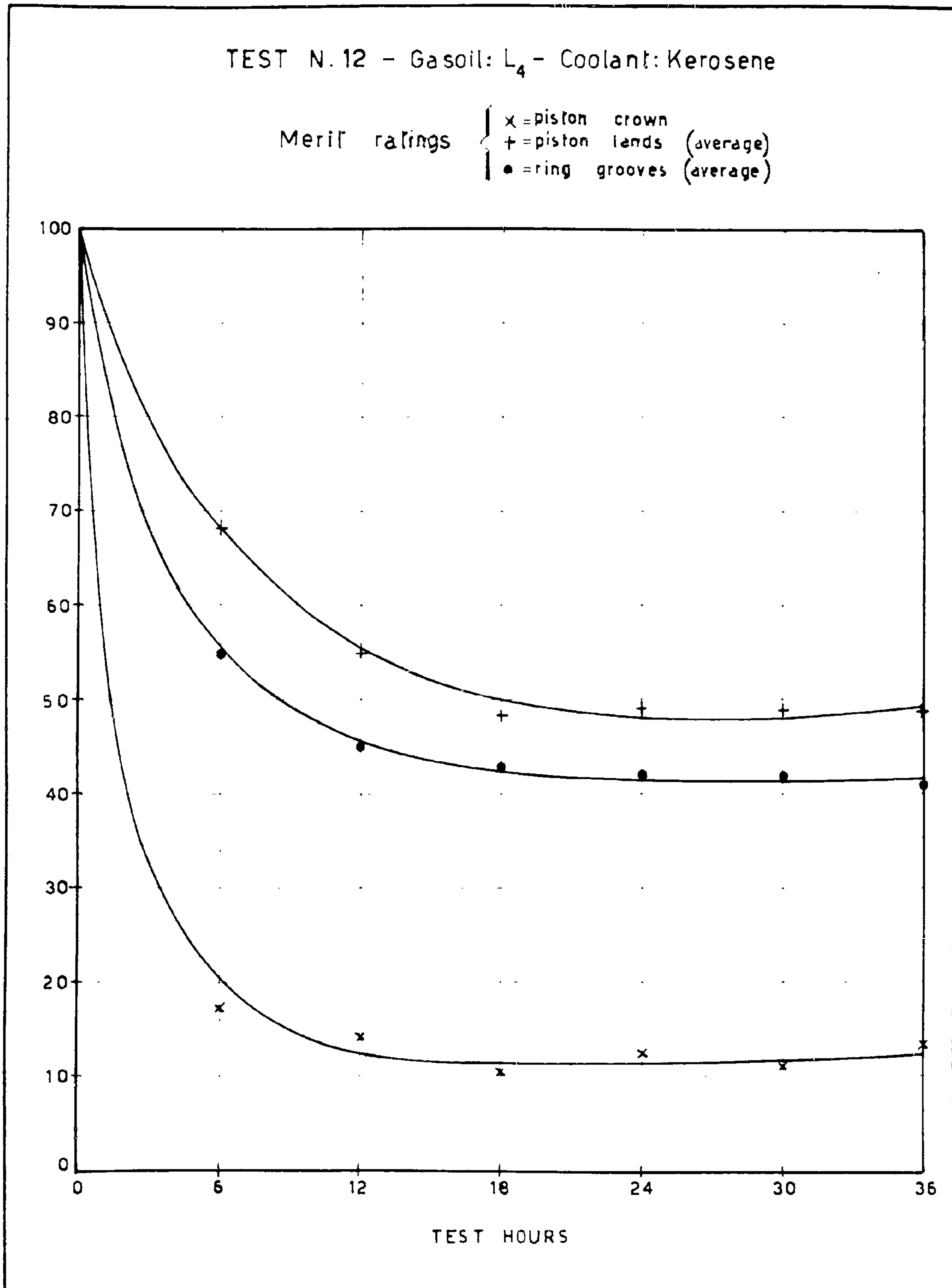


TEST N. 9 - Gasoil: P_1 - Coolant: Water
Merit ratings
× = piston crown
+ = piston lands (average)
● = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

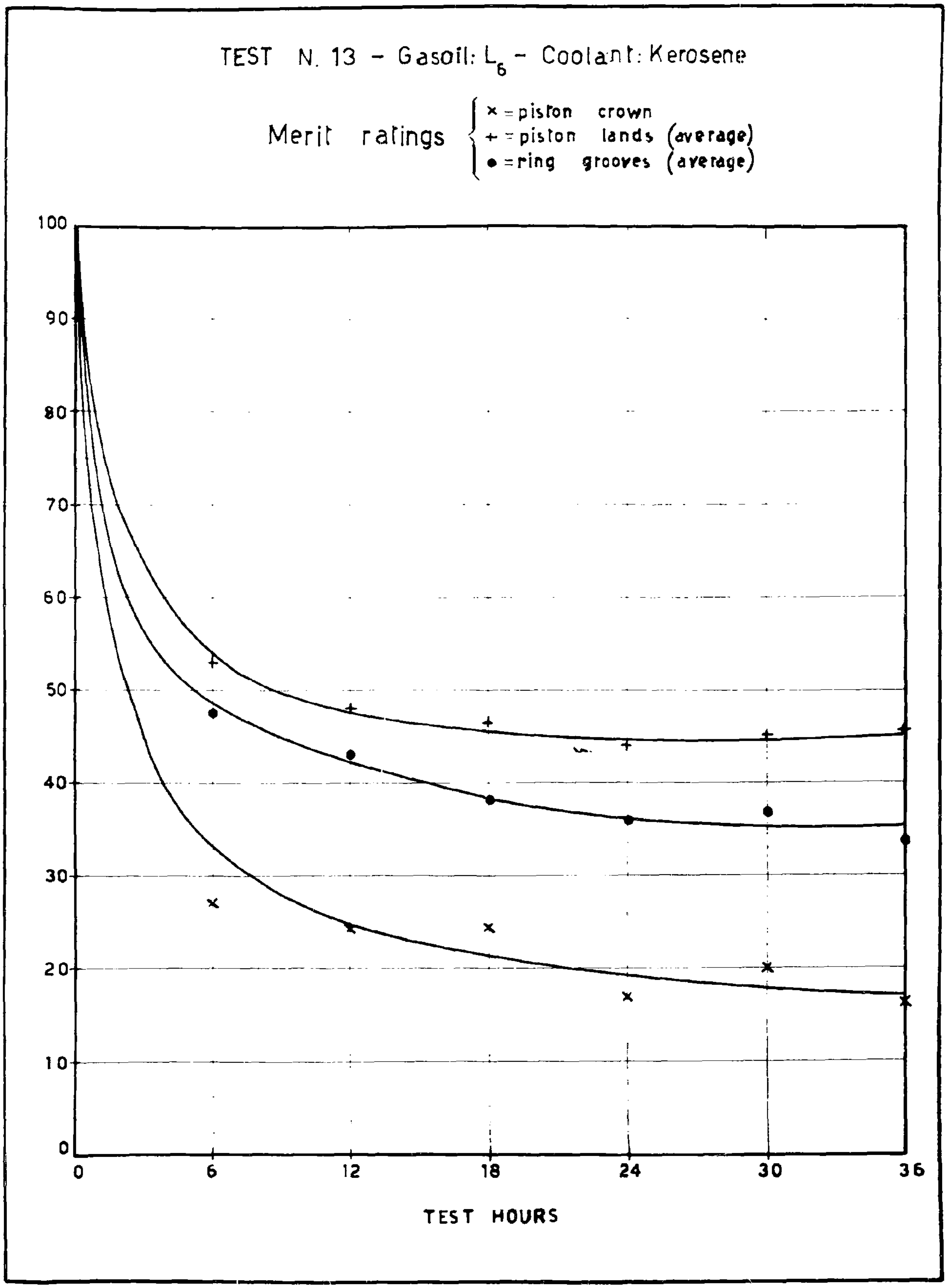


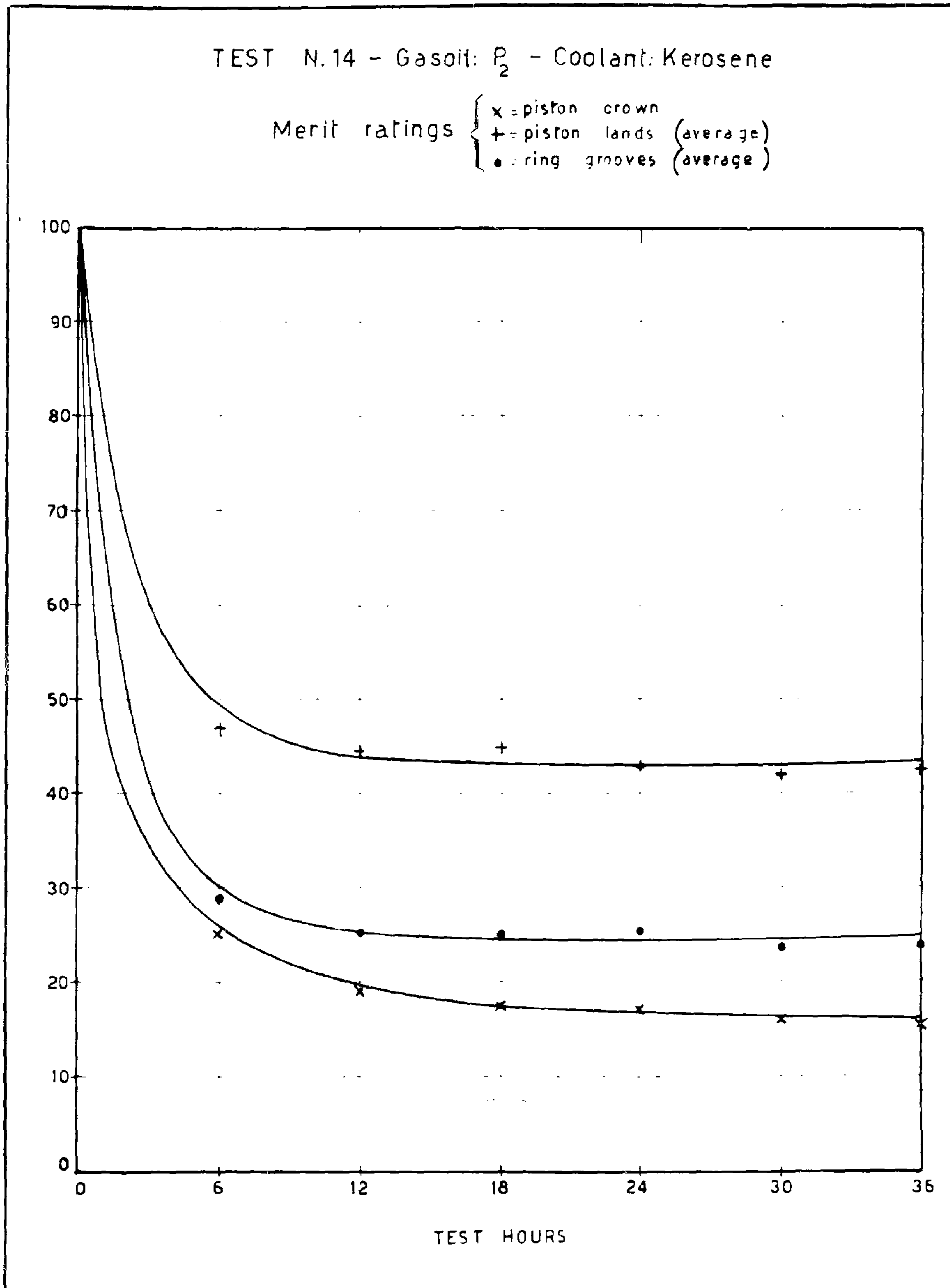
TEST N.10 - Gasoil: P_5 - Coolant: Water
Merit ratings
× = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

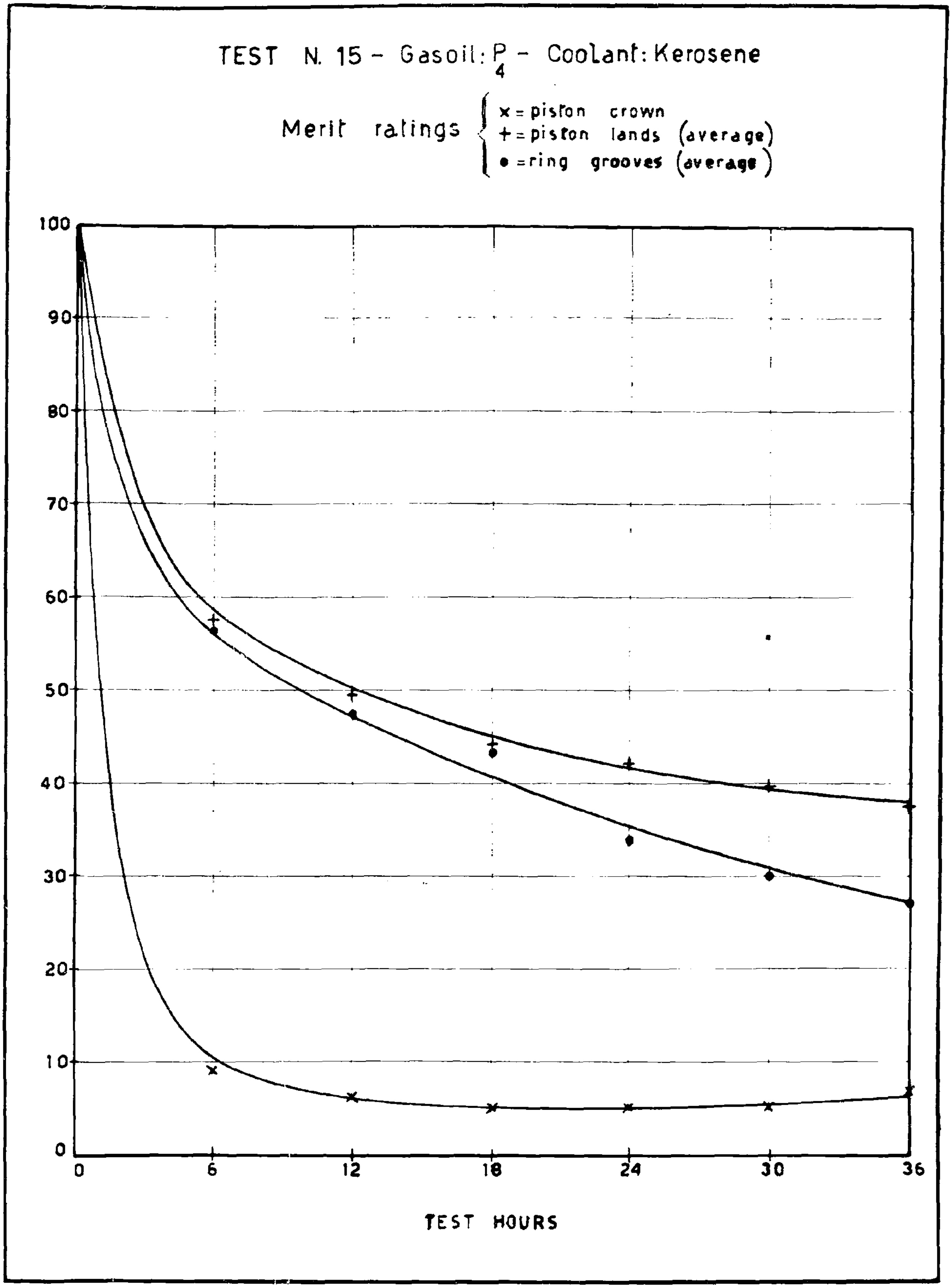

TEST N. 11 - Gasoil: L_2 - Coolant: Kerosene
Merit ratings
× = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

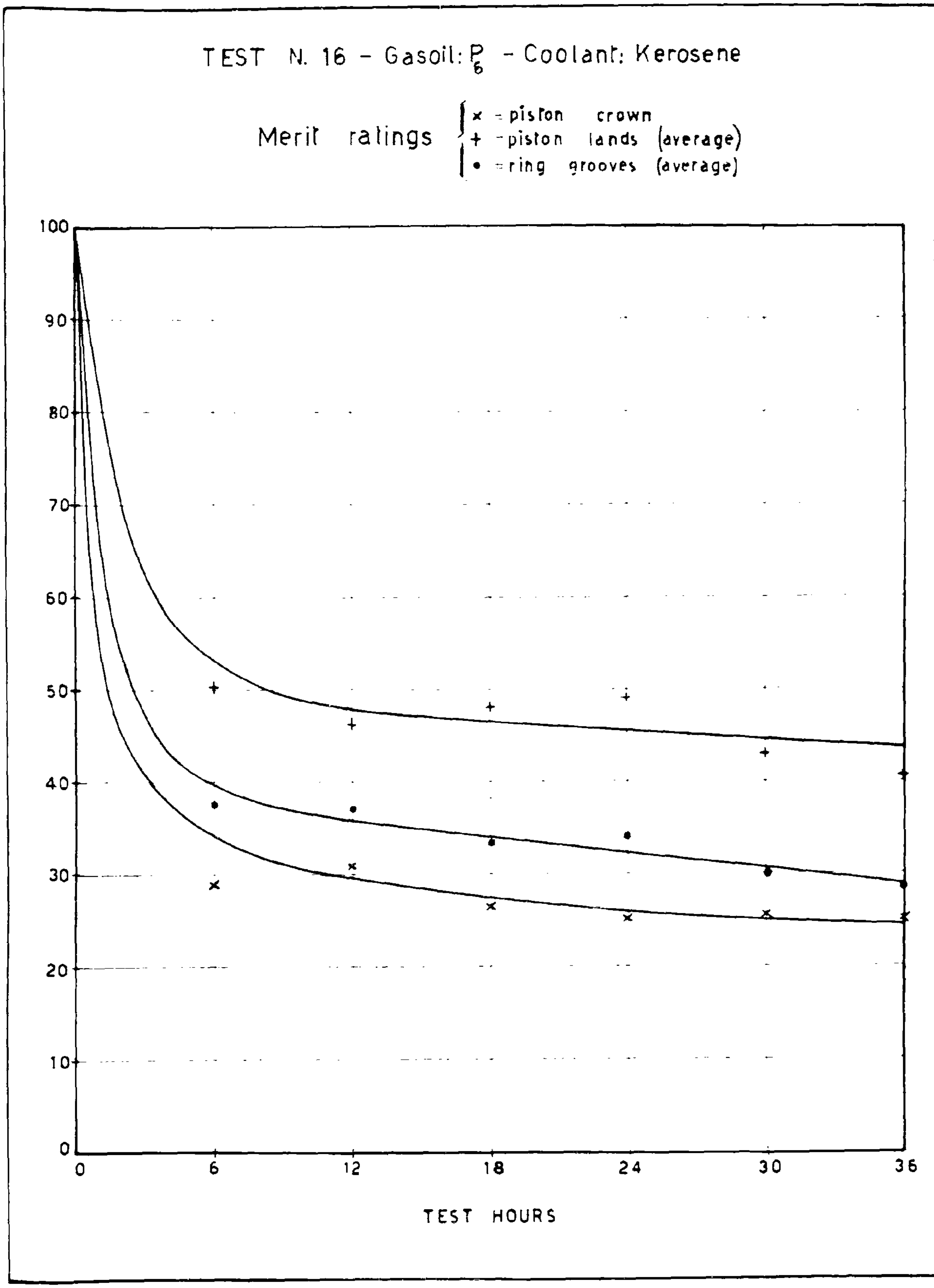


TEST N. 12 - Gasoil: L_4 - Coolant: Kerosene
Merit ratings
x = piston crown
+ = piston lands (average)
● = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

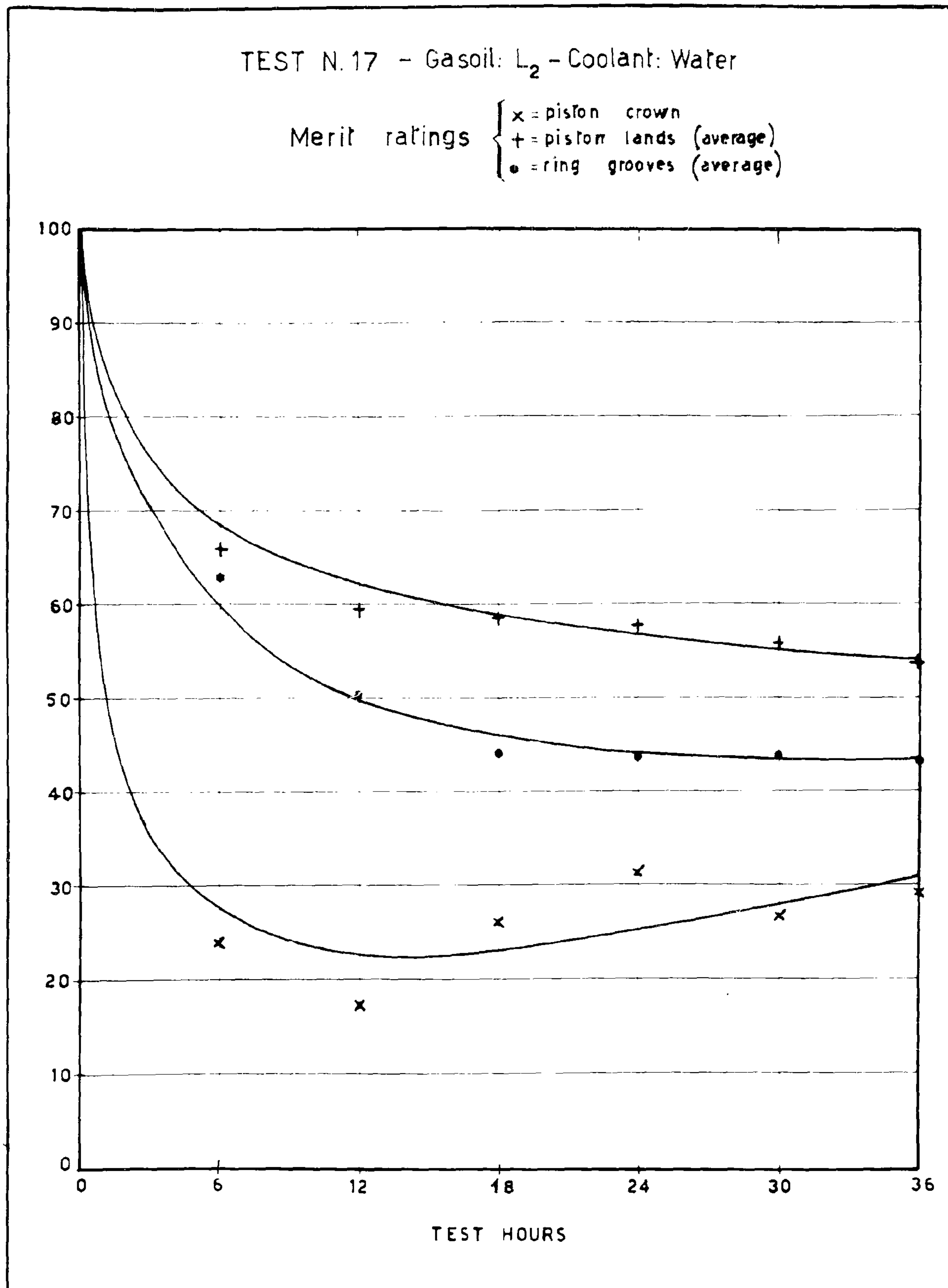

TEST N. 13 - Gasoil: L6 - Coolant: Kerosene
Merit ratings
× = piston crown
+ = piston lands (average)
● = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

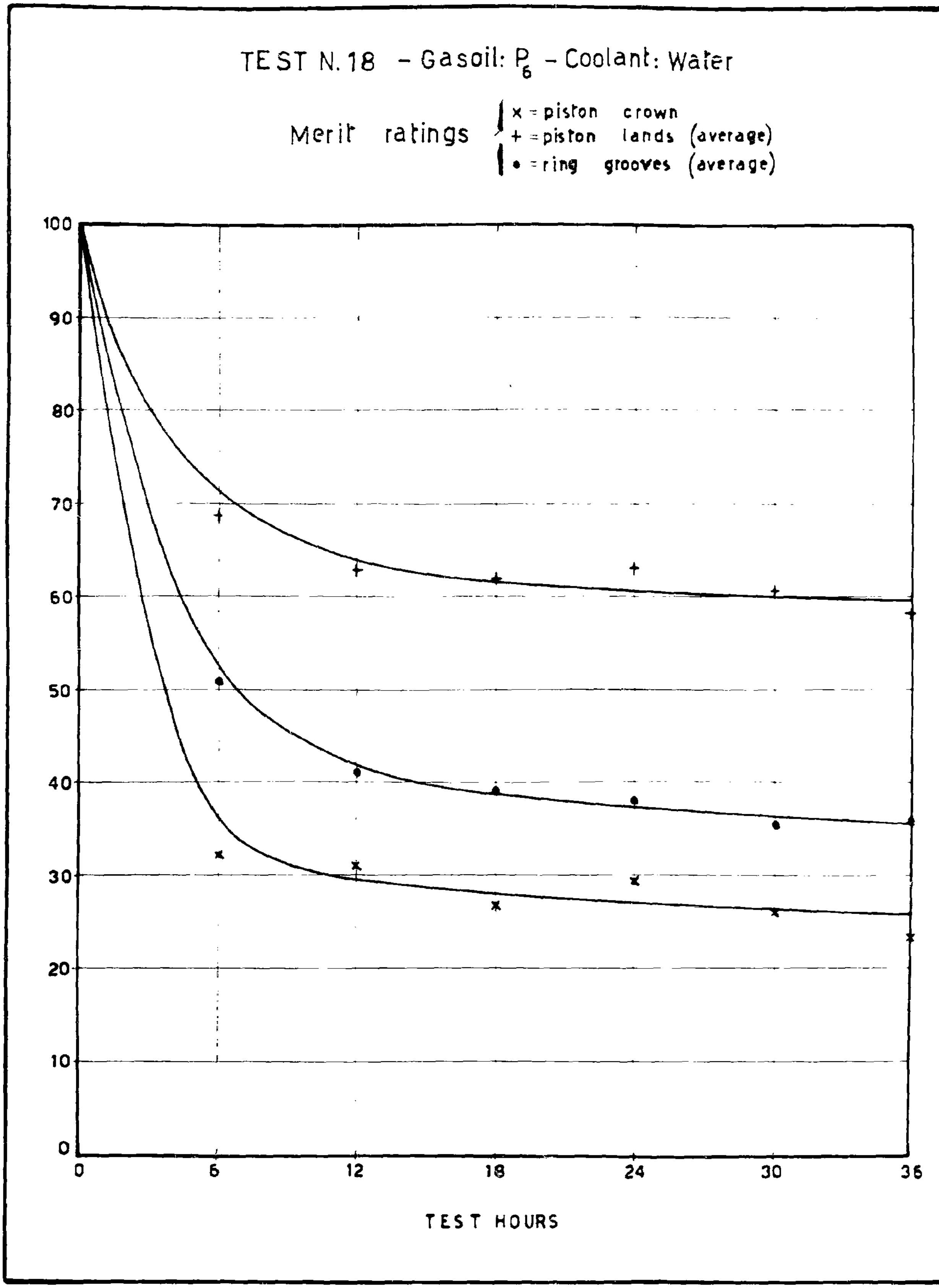

TEST N. 14 - Gasoil: P_2 - Coolant: Kerosene
Merit ratings
x = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

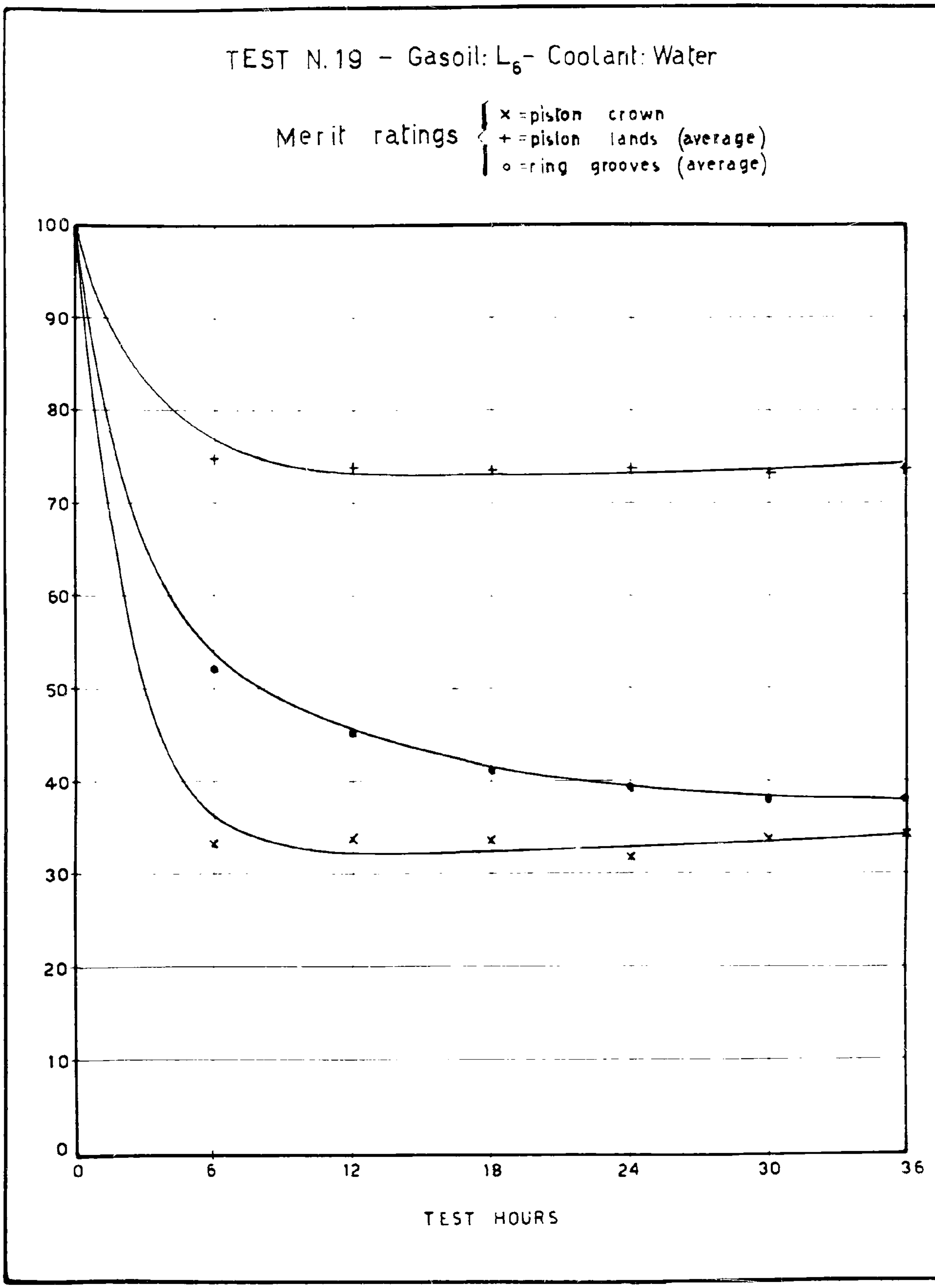

TEST N. 15 - Gasoil: P_4 - Coolant: Kerosene
Merit ratings
x = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

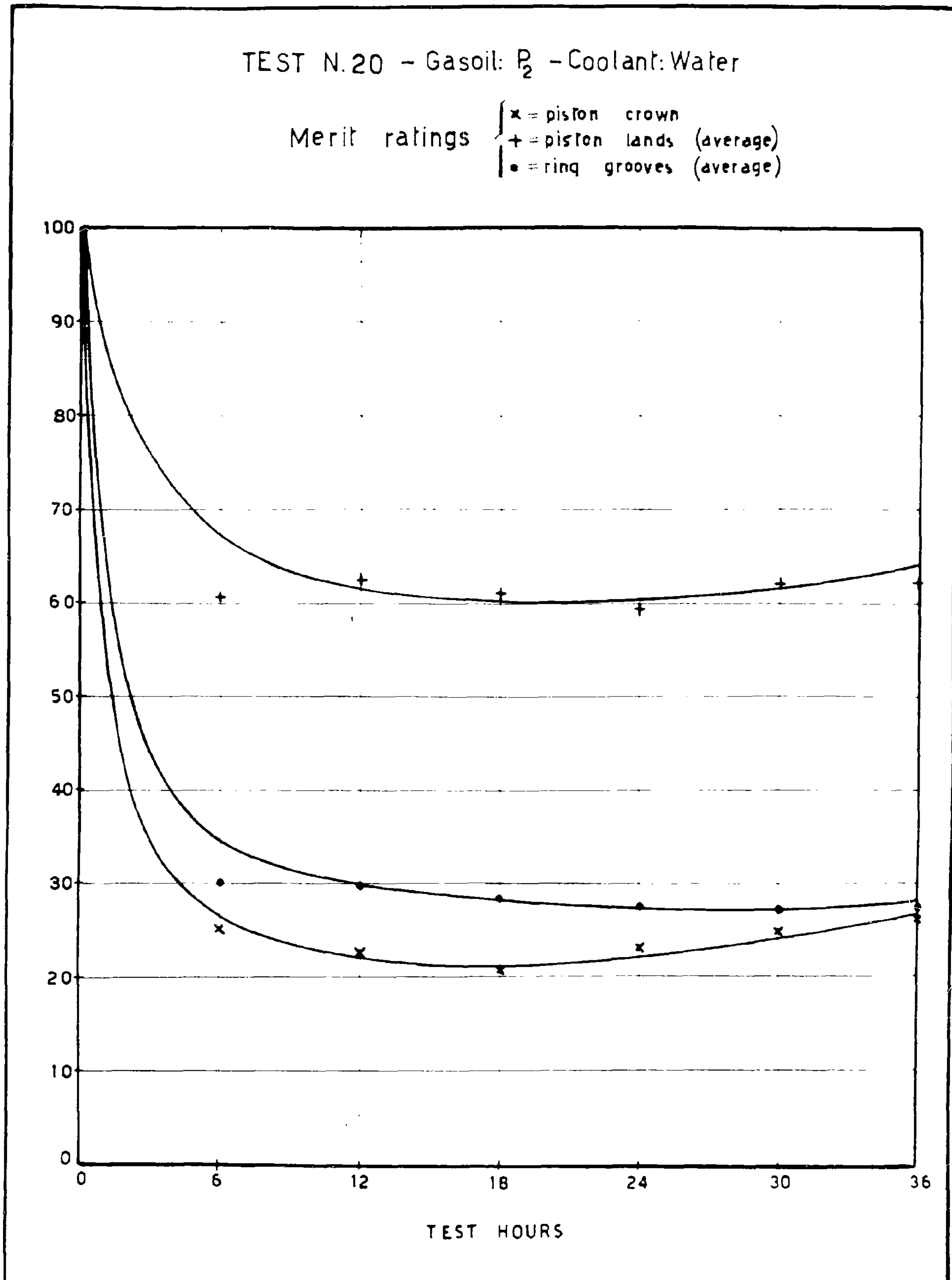


TEST N. 16 - Gasoil: P_6 - Coolant: Kerosene
Merit ratings
× = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

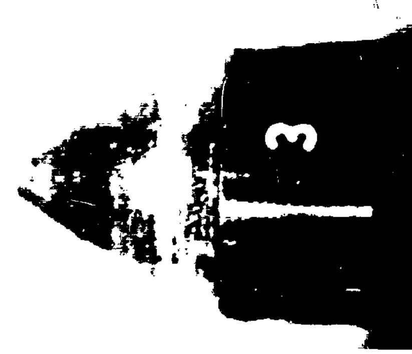

TEST N. 17 - Gasoil: L_2 - Coolant: Water
Merit ratings
x = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

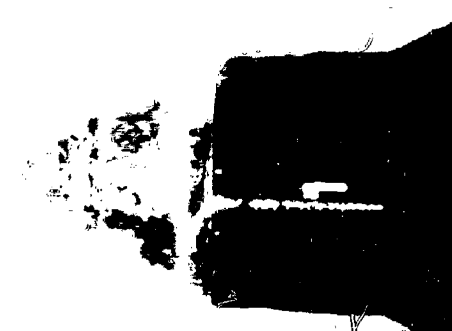

TEST N. 18 – Gasoil: P_6 – Coolant: Water
Merit ratings
x = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS

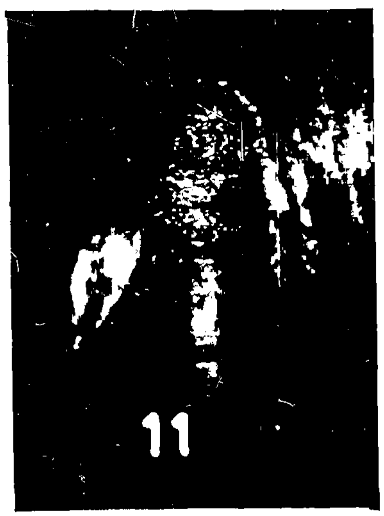

TEST N. 19 - Gasoil: L_6 - Coolant: Water
Merit ratings
x = piston crown
+ = piston lands (average)
o = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS


TEST N. 20 - Gasoil: P_2 - Coolant: Water
Merit ratings
x = piston crown
+ = piston lands (average)
• = ring grooves (average)
100
90
80
70
60
50
40
30
20
10
0
0
6
12
18
24
30
36
TEST HOURS



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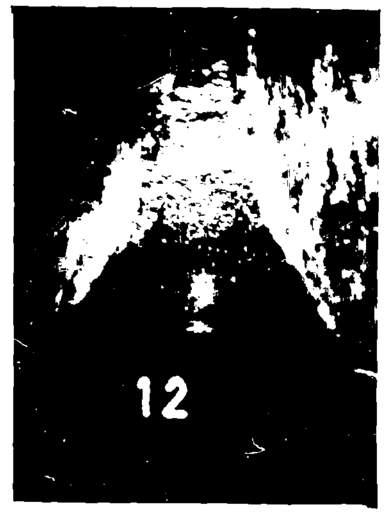
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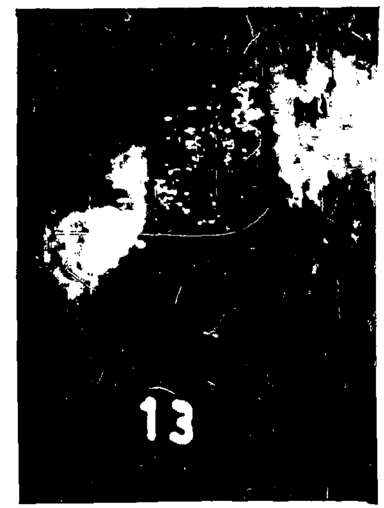
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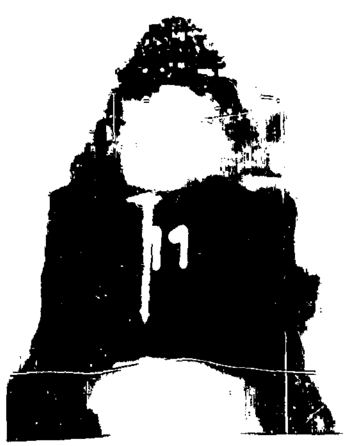
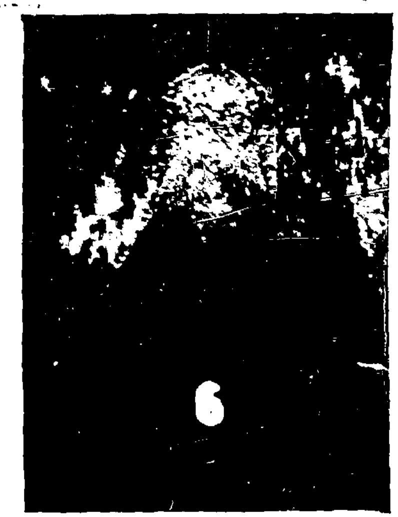

11


12


3


2

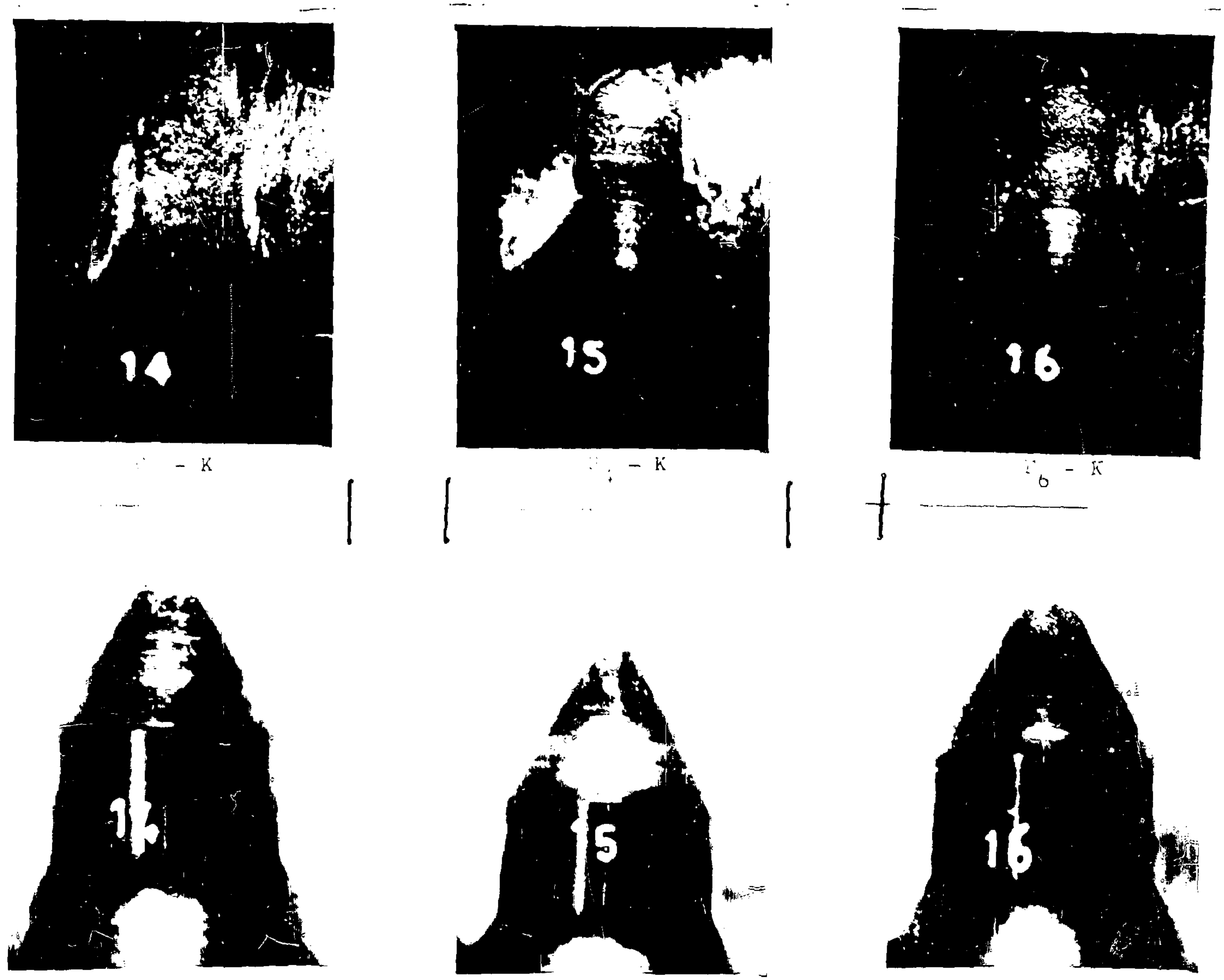

5

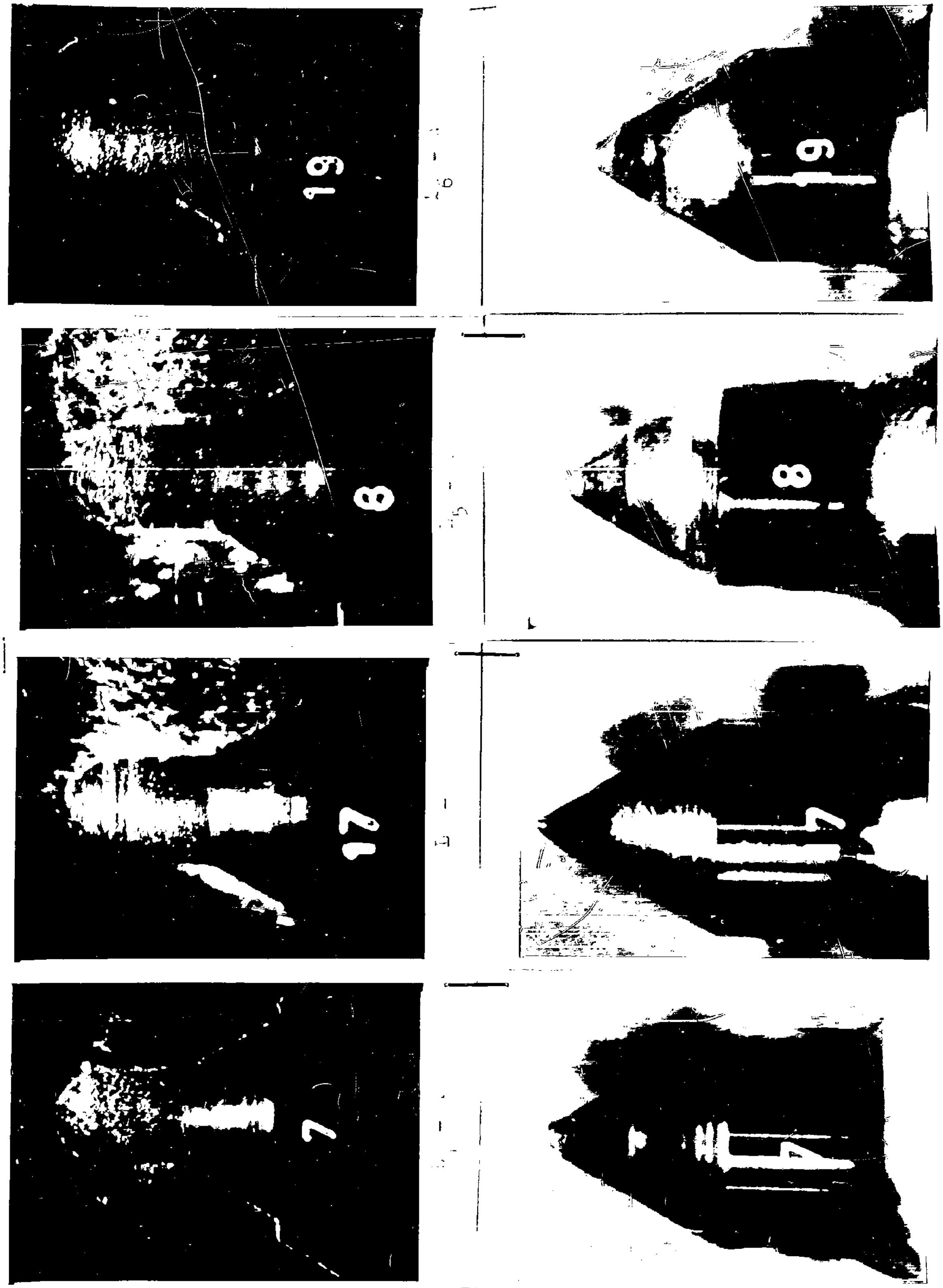

6

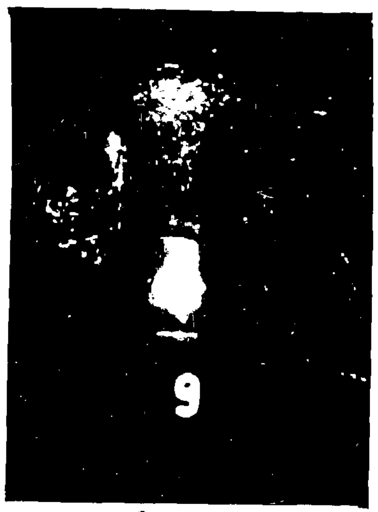

2

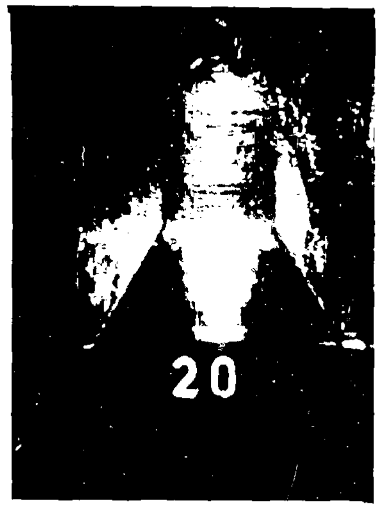

5


6


14
15
16
- K
- K
6 - K
14
15
16







F_1 – W F_2 – W F_5 – W F_6 – W